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HIGHLY LOADED MULTI-STAGE FAN DRIVE TURBINE - PERFORMANCE OF INITIAL SEVEN CONFIGURATIONS

by G. W. Wolfmeyer and M. W. Thomas

Prepared by
GENERAL ELECTRIC COMPANY
Cincinnati, Ohio 45215
for Lewis Research Center

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16. Abstract

Experimental results of a three-stage highly loaded fan drive turbine test program are presented. A plain blade turbine, a tandem blade turbine, and a tangentially leaned stator turbine were designed for the same velocity diagram and flowpath. Seven combinations of bladerows were tested to evaluate stage performances and effects of the tandem blading and leaned stator. The plain blade turbine design point total-to-total efficiency was 0.886. The turbine with the stage three leaned stator had the same efficiency with an improved exit swirl profile and increased hub reaction. Two-stage group tests showed that the two-stage turbine with tandem stage two stator had an efficiency of 0.880 compared to 0.868 for the plain blade two-stage turbine.

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SUMMARY

This report describes the experimental results of a program which was conducted to investigate aerodynamic means for increasing turbine stage loading and turbine blade loading consistent with high efficiency. Three highly loaded fan drive turbines were designed and tested: 1) a three-stage turbine using all plain blading, 2) a three-stage turbine using tandem blading, and 3) a three-stage turbine using a ten-degree tangentially leaned stator. Each turbine was designed for the same velocity diagram and each used the same constant inside diameter flowpath. Seven combinations of bladerows were tested in order to evaluate stage performances and assess the performance effects of the tandem blading and the leaned stator.

At design equivalent speed (3169.0 rev/min) and design total-to-total pressure ratio (3.47) the plain blade turbine achieved an overall total-to-total efficiency of 0.886. At design speed and pressure ratio, the leaned stator turbine achieved the same overall total-to-total efficiency while improving the turbine exit radial swirl profile. The leaned stator turbine was also successful in raising the Stage Three hub reaction from negative 20 percent to zero reaction.

Two-stage turbine tests, accomplished by removing Stage Three from the turbine, showed that the two-stage turbine using a tandem stator in Stage Two had a design point overall efficiency of 0.880 compared to an efficiency of 0.868 for a two-stage turbine using plain blading in each bladerow.

Testing conducted on stage one indicated a design point total-to-total efficiency of 0.875.

Radial efficiency profiles showed high efficiencies in the pitchline region of all configurations tested, with pronounced drop-offs in efficiency toward the hub and the tip.

Reynolds number testing accomplished by varying the inlet pressure (and thus varying the density level) indicated decreases in efficiency with decreasing Reynolds number. The turbine configurations using tandem blading experienced a larger decrease in efficiency with decreasing Reynolds number than the plain blade turbines.

INTRODUCTION

A twenty-seven month analytical and experimental investigation program was conducted to provide turbine high-stage-loading and high-blade-loading aerodynamic technology which will be specifically applicable to multistage fan drive turbine configurations for advanced high-bypass-ratio turbofan propulsion system application.

The specific objectives of this program were to:

- Investigate analytically and experimentally aerodynamic means for increasing the turbine stage loading and turbine blade loading consistent with high efficiency for multistage highly loaded fan drive turbine configurations.

- Develop sufficient design information to determine the relative importance of changes in engine size, weight, and performance and give primary consideration to use of tandem rotors and stators, where applicable, to reduce weight or extend or improve the blading performance.

- Modify an existing three-stage highly loaded turbine rig and adapt the rig to an overall performance test program of sufficient extent so as to obtain blade element performance.

The program was divided into two phases encompassing nine task items of activity. The first phase covered Task Items I through III. In Task I, requirements of selected advanced high-bypass-ratio turbofan systems were investigated, parametric turbine velocity diagram studies were carried out, and the results were reported in Reference 1. A cascade test and evaluation program was conducted under Task II, and reported in Reference 2. In Task III, the turbine flowpath was chosen and a velocity diagram was selected for three turbines: an all plain blade turbine, a turbine using tandem blading, and a turbine using tangentially leaned stators. The detailed aerodynamic and mechanical designs for the turbine and the turbine blading were performed. The turbine was scaled to utilize an existing highly loaded fan drive turbine test rig and the required rig modification drawings were prepared. Reference 3 reported the aerodynamic and mechanical design of the plain blade turbine. The tandem blade turbine design was presented in Reference 4. The design of the turbine using tangentially leaned stators was reported in Reference 5.

The second phase of the program covered Task Items IV through IX, and included the fabrication, procurement, vibration bench testing and fatigue endurance testing of the turbine blading, inspection of the turbine test rig modifications, and instrumentation and calibration of the test vehicle. In this phase of the program the testing of seven turbine configurations was accomplished, and test data was collected, reduced and analyzed. The purpose of this report is to present the results of the work performed in Phase Two of this program.

AERODYNAMIC EVALUATION

TEST VEHICLE

Requirements - The analysis and design of the three fan drive turbines which were investigated are presented in detail in References 2 through 4. An existing highly-loaded fan drive turbine rotating rig was modified for the test and performance phase of the program. The turbine design requirements were scaled for a turbine exit tip diameter of 28.4 inches in order to utilize the existing test rig. The full-size and scaled turbine design requirements are presented below:

Parameter	Full Size	Scaled
Average Pitch Loading, $\frac{gJ\Delta h}{2\Sigma U_p^2}$	1.5	1.5
Equivalent Specific Work, E/θ_{cr}, (Btu/lbm)	33.0	33.0
Equivalent Rotative Speed, $N/\sqrt{\theta_{cr}}$, (rev/min)	2000	3169
Equivalent Weight Flow, $W\sqrt{\theta_{cr}}\ \varepsilon/\delta$, (lbm/sec)	70	28
Inlet Swirl Angle (degrees)	0	0
Exit Swirl Angle Without Guide Vanes (degrees)	≤ 5	≤ 5
Maximum Tip Diameter (inches)	45.0	28.4
Number of Stages	3	3
$W\sqrt{T_T}/P_T$ at Inlet	108.4	43.16
$\Delta h/T_T$	0.0635	0.0635
$N/\sqrt{T_T}$	87.7	138.98

Configurations Tested - The three turbines investigated used the same constant-inside-diameter flowpath and velocity diagram. The turbine design velocity diagram is presented in Figure 1. The three-stage turbines were designed for stage energy splits ($\Delta h_{stage}/\Delta h_{turbine}$) of 41.7% on Stage One, 38.3% on Stage Two, and 20.0% on Stage Three. The corresponding stage aeroydnamic loadings ($gJ\Delta h/2U_p^2$) were 2.1, 1.75, and 0.82 for Stages One, Two and Three respectively. The design average pitchline loading ($gJ\Delta h/2\Sigma U_p^2$) for stages one and two grouped together was 1.92. The turbine rotating tip shroud seal teeth were designed for an interference fit with the stationary shrouds during cold buildup in order to have positive rub-in during operation and thus minimize the effects of rotor tip clearance. In order to evaluate the stage performances and assess the performance effects of the various turbine designs, seven turbine configurations were selected for testing. The configurations are described below.

Configuration	Symbol	Description
1	PPPPPP	Three-stage turbine with plain blading in all bladerows. This configuration is shown in Figure 2.
2	PPPP	Two-stage turbine with plain blading in all bladerows. This configuration is shown in Figure 3.
3	PP	One-stage turbine with plain blading in all bladerows. This configuration is shown in Figure 4.
4	PPTP	Two-stage turbine with tandem stage two stator and plain blading in all other bladerows. This configuration used the flowpath shown in Figure 3.
5	PPPPPT	Three-stage turbine with tandem stage three rotor and plain blading in all other bladerows. This configuration used the flowpath shown in Figure 2.
6	PPTPTT	Three-stage turbine with tandem stage two stator, tandem stage three stator, tandem stage three rotor, and plain blading in all other bladerows. This configuration used the flowpath shown in Figure 2. It should be noted that the tandem Stage Three stator was designed for a 24 percent reduced solidity compared to the plain Stage Three stator. The reduction in solidity was accomplished by designing 76 tandem vanes compared to 100 plain vanes for this bladerow.
7	PPPPLP	Three-stage turbine using a ten-degree tangentially leaned stator in Stage Three, and plain blading in all other bladerows. This configuration used the flowpath shown in Figure 2.

Photographs of the turbine blading used in the testing of these seven turbine configurations are presented in Figures 5 through 18.

TEST APPARATUS AND INSTRUMENTATION

Test Facility - The seven turbine configurations were tested in the General Electric Company's Evendale Air Turbine Test Facility, which is a dual purpose facility capable of evaluating either single stage high pressure turbine or multistage fan drive turbine performance. A typical test facility configuration is shown in Figure 19.

Turbine air is supplied from the Central Air Supply System of the Component Test Complex, which consists of an arrangement of five multistage centrifugal compressors driven by synchronous motors through speed increasing gears. Staging these compressors in series or parallel or using them as exhaustors provides the various modes of operation normally required for the turbine operation. The compressor discharge air is then directed through various auxiliary systems in order to provide air that is filtered to ten micron particle size, dried to minus 70° F dewpoint, and indirectly heated to the desired temperature by passing it through a heat exchanger. Flow enters the test region through a specially shaped scroll which smoothes out flow disturbances and provides a uniform stream to the test vehicle. Air enters the first stage nozzle through a convergent bellmouth section and a constant annular passage approximately three inches long. Turbine discharge air leaves through a constant annular passage approximately seven inches long and expands into the exhaust plenum.

The generated turbine horsepower is extracted by means of a high speed waterbrake direct coupled to the turbine shaft by flexible couplings and a short spool piece. This waterbrake design provides excellent speed stability throughout the entire turbine operating map.

For protection against overspeed and excessive temperature or vibrations, a two-level trip system is used. The level 1 trip is signaled by an overspeed or bearing over temperature. Level 2 is signaled by excessive vibrations, or critical support system temperatures or pressures.

The turbine facility control console is located in the Test Cell Control Room. All the necessary controls and critical turbine or facility monitoring instrumentation are strategically located to enable one man control of the entire test facility. This feature is a direct result of the utilization of analog closed-loop control circuits for setting and maintaining all prime turbine variables. Turbine parameters of inlet temperature, inlet pressure, speed, discharge pressure, and rotor net thrust can all be maintained automatically at pre-set values.

Data Acquisition System - The data acquisition system consists of a digital recorder linked to a paper tape and paper punch tape printer. The digital recording system is capable of recording up to 200 temperatures and 350 pressures in addition to other specific turbine performance parameters.

Temperature measurements are obtained with precision manufactured Chromel-Alumel thermocouple wire. Sensors in any one plane of measurement use wire from one spool. Calibration samples of wire are cut from each sensor lead and

both samples and sensor leads are oven cured for 28 hours at approximately 400° F. The wire samples are then calibrated over the expected temperature range against a Platinum Resistance Thermocouple which is traceable to the National Bureau of Standards, resulting in correction curves which are applied to the temperature measurements in the data reduction program.

Calibration curves are also established to determine temperature recovery at various expected Mach number ranges and flow incidence angles using a specially designed calibration stand with a 2.5 inch free jet nozzle capable of a Mach number range from 0.2 to 1.0. Corrections are made in the data reduction program using the calibration curves.

The thermocouple leads terminate in a Copper Alloy Thermal Sink (CATS), which is thermally insulated to minimize temperature gradients. To arrive at the absolute value of any temperature sensor, the absolute temperature of the CATS block is measured, using both a water-ice bath reference and an electronically controlled Ice Point Reference System. The latter is used to determine absolute temperature levels, but both systems are continually compared. The electrical output of each thermocouple is measured at this CATS block and the signal is amplified and directed to the digital recorder.

Turbine rig pressure measurements are obtained by the use of precision strain gage pressure transducers which convert pneumatic signals to electrical outputs. The pressures enter the control room pneumatically and terminate in electrically controlled scanners which systematically direct each pressure signal to a transducer. The transducer electrical outputs are amplified and directed to the digital recorder. All transducers of this type have a common excitation and output amplification. Each data reading contains the excitation voltage sensed at the transducer, the transducer zero, and a known calibration signal which is recorded through all its associated electrical circuitry. The repeatability of these parameters is continually monitored to preclude any measurement errors.

Pressure calibrations are performed prior to each test run using a precision dead weight tester for above-atmospheric calibrations, and a quartz manometer for sub-atmospheric calibrations. Both units are frequently calibrated and their precisions are directly traceable to the National Bureau of Standards. All pressure transducers used have characteristic curves compiled in a computer library file, to which each pre-run calibration is compared for discrepancies.

The digital recording system is linked to the General Electric 635 Computer by means of a GE Terminet 300 located in the Control Room. This feature enables reduced data to be printed out in the Control Room within five minutes of the reading of a test point.

Instrumentation - Figure 20 shows the location of the instrumentation used in the testing of the seven turbine configurations. An instrumentation scheme was used which permitted removal of downstream turbine stages without requiring the re-instrumentation of upstream stages.

Turbine inlet instrumentation was affixed to the leading edge of the inlet strut frame on each of ten struts located 36 degrees apart, and approximately ten inches upstream of the first stage stator. Turbine inlet temperature was measured with 25 Chromel-Alumel thermocouples mounted in high recovery stagnation tubes affixed to the leading edge of the inlet strut frame on each of five struts 72 degrees apart. They were located radially at the area centers of five equal annular areas. Inlet total pressure was measured with 25 Kiel-type probes located in an identical manner as the total temperatures above, but on five alternate struts 72 degrees apart. These pressures were measured independently by means of the scanner-transducer system and then arithmetically averaged in the data reduction program. They were also pneumatically averaged, using a specially designed averaging block, measuring an average output on a single pressure transducer.

Inlet static pressure was measured with five equally spaced static pressure taps located on both the inner and outer flowpaths in a straight annular section about 1.7 inches upstream of the first stage stator. These static pressure taps were used to check the circumferential uniformity of the flow and to calculate the turbine inlet total pressure.

Interstage static pressures were measured with four static pressure taps installed on both inner and outer flowpath casings, approximately 90 degrees removed, in the cavity area before and after each stator.

Turbine outlet total temperature and total pressure were measured with six fixed circumferential arc rakes 60 degrees apart, located radially at the centers of six equal annular areas, and approximately four inches downstream of the last stage rotor. A total of 36 total temperatures and 72 total pressures were measured. Each rake contained twelve Kiel-type pressure elements located side-by-side, and six shielded thermocouple elements side-by-side. The total pressures were averaged both arithmetically and pneumatically in the same manner as the inlet pressure measurements.

Six turbine outlet static pressures were measured on both the inner and outer flowpaths. Elements were spaced 60 degrees apart and were located approximately four inches downstream of the last stage rotor.

Turbine outlet total temperature and total pressure were additionally measured by a radially and circumferentially traversing combination probe. A fast response pressure differential servo-system aligned the probe with the flow and provided an electrical output proportional to the flow angle. Total temperature, total pressure and flow angle were recorded on X-Y chart recorders as functions of either radial immersion or circumferential position. The probe was located approximately one inch downstream of the last stage rotor.

Air flow to the turbine was measured using a calibrated circular arc venturi which was operated at critical flow conditions. The venturi inlet pressure and temperature were measured using wall static pressure taps and Chromel-Alumel air thermocouple probes located upstream of the venturi throat.

Three independent speed measurements were provided by an indicating system consisting of a 60-tooth gear attached to the turbine shafting and three stationary magnetic sensors located very close to the gear teeth. Electrical impulses resulting from the passing of each tooth provided an electrical frequency proportional to turbine speed. Electrically time integrating this signal provided the speed indication, accurate within $\pm$ 1 rpm. During the course of each data reading, twelve different samples of speed were recorded and arithmetically averaged.

Two independent techniques were employed for the measurement of shaft torque. The primary system consisted of a dual bridged shaft-mounted torque sensor. The strain sensitive spool section was located between the turbine shaft and the waterbrake shaft with a specially designed slip ring mounted behind the waterbrake to transmit electrical signals to the digital recorder. Each bridge was excited with its own independent electronics system and read out or displayed through the digital data acquisition system. The secondary torque measurement was obtained by means of a load cell located beneath a lever arm attached to the cradled waterbrake stator housing. The load cell also employed independent signal conditioning and readout electronics.

Torque calibrations were performed in place using a precision torque arm and dead weights, whose weight values are traceable to the National Bureau of Standards. Dead weight calibrations were conducted prior to each test run to verify repeatability of torque zeros and bridge linearity. In addition, extensive temperature calibrations were made to define torque zero and modulus changes over the operational temperature range, even though these effects are less than 0.25 percent.

TEST PROCEDURE

The turbine inlet conditions were set at 700° R and 30 psia, with a few exceptions as noted below:

- Test facility limitations on the turbine exhaust temperature required all testing of the single stage turbine (Configuration 3) to be run at inlet conditions of 660° R and 30 psia.

- Waterbrake limitations required that the low speed, high pressure ratio test points of the three-stage builds (Configurations 1, 5, 6 and 7) be run at inlet conditions of 700° R and 20 psia.

It was recognized that some Reynolds number effects would be present when operating the turbine at the reduced inlet pressure. In order to assess the Reynolds number effects additional test points, in the vicinity of the design point, were investigated at higher inlet pressures.

The performance mapping of the turbine was accomplished by selecting test points within the following range of variables:

- Speed - from 70 to 120 percent of design speed.

- Pressure ratio - from that corresponding to 50 percent design ideal enthalpy drop to a pressure ratio corresponding to approximately 113 percent design ideal enthalpy drop.

The following performance data were obtained at each test point:

- Turbine weight flow
- Rotative speed
- Torque
- Inlet total temperature
- Inlet total and static pressures
- Exit absolute flow angles
- Exit total and static pressures
- Exit total temperatures
- Flowpath hub and tip interstage static pressures

Three complete sets of data were recorded at each test point and processed through the on-line computer which permitted an immediate evaluation of the reduced data.

Key performance parameters were continually monitored to insure accuracy and consistency of the test data. The design point was periodically reset throughout the testing to monitor the repeatability of the facility and the design point calculations.

One radial and three circumferential traverses were made at each test point to record the turbine exit total pressure, total temperature and absolute flow angle. The circumferential traverses were taken at 10, 50 and 90 percent of the last stage rotor blade height.

A detailed rotor exit survey was made at the design speed and design pressure ratio for each of the seven turbine configurations tested. The survey for each configuration included seven circumferential traverses of total temperature, total pressure and flow angle at the radial centers of seven equal annular areas. The traverses encompassed at least two last stage stator wakes.

DATA REDUCTION PROCEDURE

Overall Performance - Two calculation schemes were used to reduce the overall performance data. The two methods differed in only one respect. The preliminary test cell data reduction program used measured exit total pressures for all performance calculations while the final data reduction was performed using calculated exit total pressure. This exit total pressure was calculated

using continuity by determining an integrated average flow angle from the traverses and combining it with the exit total temperature based on measured torque and the average of measured exit hub and tip static pressures.

A more detailed description of all the calculation procedures used in the data reduction may be found in Appendix A.

The following overall performance parameters were calculated for each of the three readings taken at each test point:

1. Calculated total-to-total pressure ratio as obtained from indirect measurement.

2. Calculated total-to-static pressure ratio as obtained from indirect measurement.

3. Equivalent speed.

4. Equivalent weight flow.

5. Equivalent weight flow-speed parameter (product of equivalent speed and weight flow).

6. Equivalent torque.

7. Equivalent specific work.

8. Ideal equivalent specific work.

9. Efficiency (total-to-total).

10. Blade-jet speed ratio.

These parameters are presented in Tables I through VII for turbine configurations 1 through 7 respectively.

Stage Performance - Calculations were performed to determine the efficiency of each stage of the various turbine configurations when the three stage turbine was operating at its design speed and design total-to-total pressure ratio. Design total-to-total pressure ratio for the three stage plain blade turbine (Configuration 1) was defined to be that at which the design equivalent specific work of 33.0 Btu/lbm was extracted. All stage efficiency calculations were performed with a three-stage turbine total-to-total pressure ratio of 3.47. In order to determine the stage efficiencies, it was necessary to determine the key performance parameters of the two-stage and one-stage turbine when the three-stage turbine was operating at its design point. Basic to the stage efficiency calculation was the assumption that removal of downstream turbine stages did not alter the design point performance of the two-stage and one-stage turbines, e.g., the two-stage turbine behaved identically when run by itself and when run in the three-stage turbine.

A detailed outline of the stage efficiency calculation along with a sample calculation is presented in Appendix B.

Rotor Exit Survey Calculations - The rotor exit surveys of total pressure, total temperature, and absolute flow angle, which were taken at the design point of each turbine configuration, were used to construct contour plots of local efficiency. Local efficiencies were calculated from the following parameters:

- Measured inlet total temperature
- Calculated inlet total pressure based on continuity using measured inlet static pressure and measured airflow
- Local exit total pressure measured by the traverse probe
- Local exit total temperature measured by the traverse probe

Reynolds Number Calculations - The turbine Reynolds number was varied by operating the turbine over a range of inlet pressures while maintaining the design pressure ratio. Bladerow Reynolds numbers were calculated on the basis of leaving gas velocity and throat dimension as shown in the following relationship which is in Appendix C.

$$R_{N_i} = \left(\frac{12\ W\ell}{\mu\ n d_o h_{th}}\right)_i$$

where:

W = measured airflow (lbm/sec)
μ = bladerow exit viscosity (lbm/sec-ft)
n = number of blades or vanes
h_{th} = height of bladerow at throat (inches)
i = current bladerow
d_o = bladerow throat dimension (inches)
ℓ = blade or vane suction surface length (inches)

The turbine overall Reynolds number was calculated by energy weighting the blade row Reynolds numbers in the following manner:

$$\overline{R_N} = \frac{\sum_{i=1}^{m} \Delta h_i \ R_{N_i}}{\sum_{i=1}^{m} \Delta h_i}$$

EXPERIMENTAL RESULTS AND DISCUSSION

Overall Performance - The reduced data and calculated parameters are presented in the following curves for each turbine configuration:

a. Equivalent torque versus calculated total-to-total pressure ratio.

b. Equivalent weight flow versus calculated total-to-total pressure ratio.

c. Equivalent specific work versus calculated total-to-total pressure ratio.

d. Total-to-total efficiency versus calculated total-to-total pressure ratio.

e. Total-to-total efficiency versus blade-jet speed ratio.

f. Equivalent specific work versus equivalent weight flow - speed parameter with lines of constant calculated total-to-total pressure ratio, constant speed, and constant efficiency.

The above curves utilize constant values of equivalent speed as a parameter and are shown in Figures 21 through 62.

In Figures 63 through 74, some of the reduced data for the plain blade turbine builds (Configurations 1, 2, and 3) are compared to the pre-test predictions which were originally presented in Reference 3. The data show reasonable agreement with predictions in the vicinity of the design point, with some divergence occurring at far off-design points. The predictions were made with the use of an off-design turbine computer program (Reference 6) and some disagreement was expected because of the assumptions used in the program. The computer program uses constant loss coefficients (such as bladerow efficiencies and rotor and stator total pressure recovery factors) at each operating point. The differences seen in the equivalent weight flow versus pressure ratio curves was attributed partially to the coefficients used in the computer program, and partially to variations in bladerow throat areas in the assembled hardware compared to design intent.

In Figure 75, total-to-total efficiency versus total-to-total pressure ratio for the design speed line is compared for all three-stage turbine configurations. At the design point (Pressure ratio = 3.47) the efficiencies fell within 0.003 of each other, with no turbine exhibiting a higher efficiency than the plain blade turbine (Configuration 1 - PPPPPP). The plain blade turbine retained the highest efficiency of the four turbines until the pressure ratio dropped to about 2.7. Below this pressure ratio, the plain blade turbine efficiency fell below the efficiencies of Configuration 5 (PPPPPT) and Configuration 7 (PPPPLP). In summary, while no turbine tested exhibited a higher efficiency at the design point than the plain blade turbine, two turbines (Configuration 5 - PPPPPT and Configuration 7 - PPPPLP) maintained a higher efficiency throughout a greater portion of the operating range.

In Figure 76, equivalent weight flow versus total-to-total pressure ratio for the design equivalent speed line is compared for all three-stage configurations. The curve is the same for all except Configuration 6 (PPTPTT), which had a slightly lower equivalent weight flow throughout the operating range.

Figure 77 compares total-to-total efficiency versus total-to-total pressure ratio at design equivalent speed for the two-stage turbine configurations. The gain in performance achieved by the tandem Stage Two stator turbine (Configuration 4 - PPTP) is clearly illustrated. At the pressure ratio corresponding to design equivalent specific work of the two-stage plain blade turbine (Pressure ratio = 2.66), the plain blade turbine efficiency was 0.868, while the tandem blade turbine efficiency was 0.880.

Figure 78 compares equivalent weight flow versus total-to-total pressure ratio for the two-stage turbines. The lower equivalent weight flow obtained in the three-stage and two-stage turbines which used the tandem stator in Stage Two suggests that there was a change in the Stage Two flow coefficient caused by the passage of the forward airfoil wake through the throat of the Stage Two tandem stator and by the passage of the double wake through the Stage Two rotor.

In Figures 79 through 85, curves of static pressure normalized by inlet total pressure versus axial station are presented for various turbine pressure ratios to illustrate the interstage hub and tip static pressure behavior of the turbine configurations. Figure 79 (Configuration 1 - PPPPPP) indicates that the Stage One rotor hub at lower pressure ratios had positive reaction and as pressure ratio increased, the reaction became negative. Stage One was designed for approximately eight percent positive hub reaction, while test data indicated slightly negative hub reaction at the design point. Figure 79 also indicates that the Stage Three rotor hub at lower pressure ratios had positive reaction which became negative reaction as the pressure ratio increased. In this case, the Stage Three rotor hub was designed for approximately twenty percent negative reaction. Figure 82 illustrates the influence of the Stage Three leaned stator (Configuration 7 - PPPPLP) on reaction. The leaned stator configuration turbine had a positive reaction Stage Three rotor throughout its entire operating range.

Stage Performance - Stage performance calculations were performed in order to isolate and assess the effects of the tandem and leaned stators and the tandem rotor when the turbine was operating at its design speed and pressure ratio. Table VIII summarizes the stage performances.

Stage One was not significantly affected at the design point by the various downstream configurations which were tested.

The most significant performance gain relative to the plain blade turbine was the increase in efficiency achieved by the Stage Two tandem stator. The stage efficiency calculations show Stage Two with the tandem stator had a total-to-total efficiency of 0.873 compared to 0.846 for Stage Two with the plain blade stator.

The cascade tests performed in conjunction with the turbine rotating tests and reported in Reference 2 give an indication of the reasons for this significant difference in efficiency. Cascade testing of the Stage Two plain stator hub section showed a high sensitivity to positive incidence angle due to separation from the suction surface at about 0.8 of the vane axial width at

positive incidence angles. The Stage Two tandem stator had less sensitivity to positive incidence angle with no evidence of separation. The tandem stator hub section tested also achieved exit angles closer to design exit angle than the plain stator section. This allowed the Stage Two rotor to do more turning and thus extract more work.

Another significant result was that the Stage Three reduced solidity tandem stator paired with the Stage Three tandem rotor in Configuration 6 (PPTPTT) had an efficiency of 0.856 compared to 0.918 for the plain stator - tandem rotor Stage Three used in Configuration 5 (PPPPPT) and 0.923 for the plain stator-plain rotor Stage Three used in Configuration 1 (PPPPPP). This decrease in efficiency was mainly attributed to the effect of the reduced solidity stator; however, it is speculated that some of the decrease in efficiency was due to the interaction between the two tandem bladerows.

It is interesting to note the comparison between the plain blade turbine (Configuration 1 - PPPPPP) with a design point overall efficiency of 0.886 and the turbine using tandem blading in Stage Two stator, Stage Three stator and Stage Three rotor (Configuration 6 - PPTPTT) with a design point overall efficiency of 0.883. Even though the reduced solidity tandem stator-tandem rotor Stage Three was relatively low in efficiency, the tandem stator-plain rotor Stage Two was high enough in efficiency to enable the overall turbine efficiency to be down only 0.003 relative to the plain blade turbine. This could be an important factor when trade-offs between weight and efficiency can be considered.

The Stage Three leaned stator used in Configuration 7 (PPPPLP) had no influence on the Stage Three efficiency or on the overall turbine efficiency at the design point compared to the plain blade turbine. However, a significant result of the use of the leaned stator was observed in the reduction in the turbine exit swirl gradient compared to the plain blade turbine. This was a result of the improved hub to tip static pressure gradient at the leaned stator exit. Another significant result was the achievement of near zero reaction across the Stage Three rotor hub. These effects are illustrated in Figures 86 through 88.

Rotor Exit Survey - Turbine efficiency contour plots showing local efficiency as a function of radius ratio and circumferential position for each turbine configuration design point are presented in Figures 89 through 95. These plots are useful for observing trends in so far as they indicate the regions of high efficiency at the pitchline between the last stage stator wakes and the regions of low efficiency in the vicinity of the tip, with a large decrease in efficiency toward the hub.

The temperature and pressure data used to construct these plots were manually read from the X-Y charts produced by the traversing survey probe. The accuracy of this technique is only sufficient to determine local trends and not absolute level of local efficiency; thus, the reader is cautioned against drawing conclusions about the relative performance of the various turbine configurations from these contour plots.

Figures 96 through 98 compare the local turbine total pressure ratio as a function of circumferential location for the three stage turbine groups. It is interesting to note that the stator wakes in the hub region only appeared behind the configuration with the tangentially leaned stator in the third stage. Based on this information it was concluded that the other three-stage configurations had local boundary layer separation at the hub.

The conclusion of local boundary layer separation at the turbine hub is also substantiated in Figures 99 through 101 which show the turbine exit flow angle as a function of circumferential position. These figures indicate that the flow experienced more turning in the three-stage configuration which had the leaned stator in the third stage.

Radial Efficiency Profiles - Radial efficiency plots showing average circumferential efficiency for each turbine configuration design point are presented in Figures 102 through 106. The total temperatures and total pressures measured by the six fixed exit circumferential arc rakes and recorded by the digital recording system were used to calculate average local efficiencies.

In Figures 102 through 104 the radial efficiency profile of the three-stage plain blade turbine (Configuration 1 - PPPPPP) is compared with each of the other three-stage turbines. The efficiency of Configuration 5 (PPPPPT) was slightly higher from hub to pitch, and fell below Configuration 1 from pitch to tip. The overall efficiency of Configuration 5 was slightly lower than the plain blade turbine. During the design phase of the Stage Three tandem rotor it was believed that tandem blading would improve bladerow performance in the hub region, but not much benefit would be obtained from tandem blading in the tip region. Therefore, the tandem rotor blade was designed with a decreasing tangential gap between forward and aft airfoils from hub to tip such that the two airfoils merged at the tip. The results of the cascade testing reported in Reference 2 indicated that there was a change in bladerow efficiency with a change in tangential gap. The radial efficiency profile seems to indicate that a penalty was sustained in the pitch to tip region because of the decreasing tangential gap. Configuration 6 (PPTPTT) had slightly higher efficiency than Configuration 1 from the hub to about 30 percent of the exit height. From there to the tip the efficiency was considerably lower. The overall efficiency of Configuration 6 was 0.003 below that of the plain blade turbine. The leaned stator turbine (Configuration 7 - PPPPLP) had higher efficiency from hub to pitch, but was lower from pitch to tip. The overall efficiencies of the leaned and plain turbine were the same at the design point.

Figure 105 compares radial efficiency profiles of the two-stage turbines. The profile shapes are similar, but the plain blade turbine (Configuration 2 - PPPP) profile is lower than that of the tandem turbine (Configuration 4 - PPTP) throughout the entire turbine exit height. The two profiles have the greatest divergence in the hub region, indicating that much of the gain in overall performance by the tandem turbine was achieved in this region. The tandem turbine design point efficiency was 0.880 compared to 0.8675 for the plain turbine.

The radial efficiency profile of the single stage turbine is shown in Figure 106. The profile shows that the turbine was more efficient in the upper half of the flowpath than in the lower half.

The radial efficiency profiles for each turbine configuration show high efficiencies with pronounced drop-offs in efficiency toward the hub and the tip. This is an indication of the effects of strong secondary flowfields generated by the high turning bladerows. The pitchline efficiency is a measure of the full potential of each bladerow. Additional improvements in the hub and tip areas are required to enable the bladerows to utiilize their full potential.

Reynolds Number Effects - The turbine Reynolds number was varied by operating the turbine over a range of inlet pressures (thus changing the density level) while maintaining a constant turbine pressure ratio.

In Figures 107 through 113 plots of total-to-total efficiency versus blade-jet speed ratio at constant total-to-static pressure ratio and various inlet total pressures are presented for each turbine configuration. These plots illustrate the effects of changing inlet pressure on turbine efficiency as the turbine operates through its speed range. With each increase in turbine inlet pressure (and corresponding increase in turbine Reynolds number) the increase in efficiency becomes smaller until at some point, no further increase in efficiency should be obtained. The curves indicate that this point was not reached in test.

Plots of total-to-total efficiency as a function of turbine Reynolds number for three-stage, two-stage, and one-stage turbine groups are presented in Figures 114 through 116. Plots of equivalent weight flow versus turbine Reynolds number for the same turbine groups are presented in Figures 117 through 119. Each point on the plots represents data obtained at or near the design operating point. Several observations about the plots can be made:

1. There is a decrease in design point efficiency and equivalent weight flow as turbine Reynolds number is lowered.

2. The turbine configurations which used tandem blading experience a larger decrease in efficiency and equivalent weight flow with decreasing Reynolds number than the plain blade turbines.

3. There appears to be a relationship between change in efficiency and change in equivalent weight flow as a result of change in Reynolds number.

Figures 117 and 118 show that the configurations containing the tandem stator in Stage Two have lower equivalent weight flows than those configurations using the plain Stage Two stator. As discussed previously, this was attributed to a lower stage flow coefficient caused by the tandem airfoil wakes.

Figure 116 shows that the single stage turbine experienced a larger decrease in efficiency with decreasing Reynolds number than the three-stage and two-stage turbines. The curve of equivalent weight flow versus Reynolds number for the single stage turbine (Figure 119) appears to be consistent with the three-stage and two-stage turbine curves. It appears that factors other than Reynolds number were present since the decrease in equivalent weight flow was consistent with three-stage and two-stage results, while efficiency was not. One factor contributing to the lower than expected single stage turbine performance at the lower Reynolds number operating points was the increased percentage of the turbine horsepower being absorbed by the turbine bearings and windage losses external to the turbine.

Recommended Improvements - The analysis of the data taken during the two dimensional cascade tests and the rotating cold air turbine tests clearly indicate the areas of performance deficiencies within the turbine. Several recommendations to improve the overall performance of this three-stage highly loaded fan drive turbine based on these test results are described below:

1. Operate the three-stage plain blade turbine with the tandem Stage Two vane. It is predicted that this will increase the overall performance of the turbine by one percent.

2. Operate the turbine with the leaned Stage Three stator ahead of the tandem Stage Three rotor. This will produce a positive reaction at the hub and thus provide the rotor with a more favorable flow field in which to operate.

3. Design and test a tandem Stage Three stator with the same solidity as the plain Stage Three stator. This will establish whether the losses observed in Configuration 6 (PPTPTT) were due entirely to the reduced solidity Stage Three tandem stator or due partially to an interaction between the tandem stator and the tandem rotor blade.

4. Design and test a tandem Stage Two blade since this blade operates in a stage with high turning stator and rotor airfoils which produce 38 percent of the total turbine output as compared to the third stage which only produces 20 percent of the total output and has less turning in its bladerows.

The radial efficiency profiles indicate higher levels of efficiency in the pitch region with a large fall off toward the hub. In order to improve the overall efficiency of these stages additional techniques must be developed to diminish the effects of the strong hub region secondary flow fields generated by the high turning bladerows.

MECHANICAL EVALUATION

The plain and tandem rotor blades were vibration and fatigue tested under laboratory conditions to substantiate the analytical effort reported in References 3 and 4, and to experimentally insure the integrity of the blades in an air turbine environment through the examination of possible failure regions and corresponding stress levels.

LABORATORY TEST OF PLAIN BLADE AIRFOILS

Bench Frequency and Nodal Pattern Determination - As a means of substantiating the predicted plain blade natural frequencies reported in Reference 3, a laboratory determination of these frequencies and the corresponding nodal patterns was undertaken. This effort included the determination of fundamental and higher order frequency modes for both cantilevered (restrained at the hub and free at the tip) and fixed-fixed (restrained at the hub and the tip) conditions. The restraints used in testing under these conditions are illustrated in Figure 120.

Campbell Diagrams incorporating the most probable and higher order complex modes are presented for each stage in Figures 121 through 123. The restraining conditions most likely to represent the air turbine behavior of the blades were chosen to arrive at the most probable modes of vibration. Centrifugal stiffening and temperature versus speed effects on blade frequency were neglected. It should be noted that the figures compare predicted and test frequencies for all the fundamental modes except the flexural modes. Predicted frequencies for the flexural modes include slipping between adjacent tip shrouds, a condition which could not be simulated in the laboratory. Thus, no valid comparisons could be made. The test frequencies for the axial and torsional modes were in good agreement with predicted values, lending credence to the predicted flexural mode frequencies. The importance of the presence of the complex higher order modes within the turbine operating range was diminished by the fact that substantial past experience with other blading has shown that these modes normally require higher amounts of energy to drive and thus become less significant relative to the fundamental modes. Since the laboratory test results for the fundamental modes were in close agreement with the predicted values, the discussion of the fundamental mode resonances within the turbine operating range presented in Reference 3 remained valid, and it was concluded that the blades would not experience any excessive vibration during air turbine operation.

Bench Fatigue Endurance Testing - A bench fatigue endurance test was performed on samples of each rotor bladerow in order to establish the fatigue characteristics of the AISI 410 Stainless Steel in the machined hardware configuration relative to polished barstock specimens established as the norm, and to determine relatively weak areas on the blades.

As shown on the Campbell Diagrams for each stage (Figures 121 through 123) the resonances with the first flexural mode occur closest to the design speed, and thus pose the greatest threat to successful operation of the turbine.

Hence, the blades were fatigue tested in the first flexural mode. Although the first flexural mode could not be exactly simulated in the laboratory, a portion of the blade behavior in this mode was simulated by fatigue testing under cantilevered boundary conditions. This accounts for the differences between predicted first flexural frequencies presented in the Campbell Diagrams and laboratory blade frequencies shown in Table IX. Since true operating conditions were not simulated, the test data should be used only in a qualitative manner. Fatigue testing was conducted at room temperature. Stress levels were selected, and the blades were cycled to failure. If no failure occurred within one million cycles (run out), the stress levels were increased and the blades were re-cycled to failure. The results of the testing, including failure location, cycles to failure, and maximum stress on the blades at the time of failure, are presented in Table X. Photographs of the blade failures are presented in Figures 124 and 125.

The laboratory fatigue data compared favorably with the average fatigue characteristics for AISI 410 Stainless Steel. The material in a machined blade configuration suffered little or no fatigue strength deterioration relative to the polished barstock specimens established as the norm. It was concluded that the plain rotor blades had no inherently weak points and had sufficient fatigue endurance capability for successful air turbine operation.

LABORATORY TEST OF TANDEM BLADE AIRFOILS

Bench Frequency and Nodal Pattern Determination - Because of the complexity of the shrouded tandem blade configuration in an air turbine environment from a vibratory standpoint, attempts to simulate the precise behavior of the shroud under laboratory conditions were extremely difficult. To a first approximation, this behavior was most closely represented by a combination of results attained by testing the airfoils under cantilevered conditions (fixed hub and free tip) and fixed-fixed conditions (fixed at the hub and fixed at the tip). Natural frequencies and their corresponding nodal patterns were thus recorded for both fixed-fixed and cantilevered conditions.

For both the fixed-fixed and the cantilevered conditions, frequencies were determined for the case of the aft airfoil being excited in one of its natural frequencies (and thus possibly driving the forward airfoil through geometric and mechanical coupling), and for the case of the forward airfoil being excited in one of its modes. Both possibilities exist under actual operating conditions. The purpose of this phase of the testing was to determine whether, if one of the airfoils were to vibrate in its natural frequency, the excitation would be strong enough to carry the other airfoil to significant vibratory levels. It was concluded from the testing that this behavior would indeed exist.

Campbell Diagrams showing the significant most probable modes of vibration are presented in Figures 126 and 127. Since in air turbine testing, the tandem rotor was preceded by a 100 vane stator (Configuration 1 - PPPPPP and Configuration 5 - PPPPPT) and also a 76 vane stator (Configuration 6 - PPTPTT), Campbell Diagrams containing the known stimuli for each case are presented

for convenience. Only results for fixed-fixed testing are included for the forward airfoil motion since the shroud and dovetail are so massive relative to the airfoil. For the aft airfoil, a combination of fixed-fixed and cantilevered results is presented. The higher order complex modes of vibration have been omitted as was done in the plain blade evaluation.

The several possible resonance points indicated by Figures 126 and 127 were examined to determine their effect on successful operation of the tandem blade air turbine. As was the case with the plain blade evaluation, the first flex mode is the only fundamental mode which is resonant within the operating range near the design speed. The other resonances were determined to be less significant either because the modes are more difficult to drive or because the modes are in resonance with subharmonics of the third stage stator stimulus and thus relatively weak in nature. Therefore, the first flex mode of vibration was chosen for further investigation in the fatigue endurance testing.

During the design phase of the program, it was concluded that a pin connecting the forward and aft airfoils near the pitchline was necessary to insure the dynamic stability of the tandem blade during air turbine testing. The two airfoils were joined by "half-pins" which were machined onto the airfoils during manufacture and brazed together at assembly. Concern was expressed about the vibratory behavior of the tandem blades if the braze joint at the pin should break. Such an event occurred during vibration testing of the blades, and it was found that the separated blades were very hard to drive to any significant amplitude. This was believed to be due to the damping of motion caused when the pin halves banged together. Thus, it was concluded that separation at the braze joint would not present a problem.

Bench Fatigue Endurance Testing - Because of the complex geometry in the pin region and the sharp edges in the hub and tip shroud regions, it was decided that fixed-fixed clamping conditions would yield fatigue testing results most representative of possible tandem blade behavior in the air turbine. The tandem blades were then cycled in the first flexural mode of vibration at room temperature. Since the scope of the program was not broad enough to include the testing of a large sample of tandem blades at temperatures and boundary conditions representative of true air turbine operating conditions, the results were used only in a qualitative manner.

The results of the fatigue testing, including failure location, cycles to failure, and maximum stress at the time of failure, are presented in Table X. Photographs showing a typical fatigue crack on the leading edge of the forward airfoil just under the tip shroud are presented in Figures 127 and 128. As indicated in the table, some failures at the pin braze joint occurred during the testing. The effect of pin braze joint failure on vibratory stress levels was previously discussed. Once the pin braze fails, it is not clear that any further failure propagation will occur. On the other hand, once a crack forms in the parent blade material, it will propagate rapidly. For these reasons, failures at the pin braze joint were rebrazed and the testing was continued until a failure occurred in the parent material. It is appropriate to note that inspection of the pin braze joints after air turbine testing revealed that no such pin separations occurred during actual rotating testing.

On the basis of the vibration and fatigue endurance testing of the tandem blades, it was concluded that the blades had sufficient fatigue endurance capability for successful operation in the air turbine.

SUMMARY OF RESULTS

Three highly loaded fan drive turbines were designed and tested: (1) a three-stage turbine using all plain blading, (2) a three-stage turbine using tandem blading, and (3) a three-stage turbine using a ten-degree tangentially leaned stator. Each turbine was designed for the same velocity diagram and each used the same flowpath. Seven turbine configurations were tested in order to evaluate the stage performance and assess the performance effects of the three turbine designs. The most significant results of the testing and evaluation are summarized below:

1. At the design speed and pressure ratio (P_{T0}/P_{T3} = 3.47, $N/\sqrt{\theta_{cr}}$ = 3169.0) the plain blade turbine (Configuration 1 - PPPPPP) achieved an overall total-to-total efficiency of 0.886.

2. At the design speed and pressure ratio, the leaned stator turbine (Configuration 7 - PPPPLP) also achieved an overall total-to-total efficiency of 0.886 while at the same time achieving a significantly improved exit radial swirl profile. The leaned stator turbine was also successful in raising the Stage Three hub reaction from negative 20 percent to zero reaction.

3. While no three-stage turbine configuration achieved greater design point efficiency than the plain blade turbine, two turbines (Configuration 5 - PPPPPT and Configuration 7 - PPPPLP) maintained higher efficiency than the plain blade turbine throughout a greater portion of the operating range.

4. Stage performance calculations showed that the reduced solidity tandem stator in Stage Three caused a significant decrease in stage efficiency compared to the plain blade nominal solidity stator stage. (Plain stator-tandem rotor Stage Three efficiency was 0.918; tandem stator-tandem rotor Stage Three efficiency was 0.856).

5. The two-stage configuration incorporating the tandem stator in Stage Two achieved a design point efficiency of 0.880 compared to 0.868 for the two-stage plain blade turbine.

6. Stage performance calculations showed that Stage Two with the tandem stator had a stage efficiency of 0.873 compared to a stage efficiency of 0.846 for the plain Stage Two.

7. The one-stage configuration achieved a design point total-to-total efficiency of 0.875.

8. Radial efficiency profiles showed high efficiencies in the pitchline region, with pronounced drop-offs toward the hub and the tip. The leaned stator turbine had improved efficiency in the hub region but lower efficiency in the tip region compared to the plain blade turbine.

9. Results of Reynolds number testing accomplished by varying turbine inlet pressure (and thus varying density level) indicated decreases in design point total-to-total efficiency with decreasing Reynolds number. The turbine configurations using tandem blading experienced a larger decrease in efficiency with decreasing Reynolds number than the plain blade turbines.

APPENDIX A

OVERALL PERFORMANCE CALCULATION

Flow Angle - In order to evaluate turbine performance on the basis of turbine exit total pressure calculated from continuity, an average turbine exit flow angle was determined. The turbine exit flowpath was divided into streamtubes, and measured values of swirl angles, total pressure, and total temperature were used to satisfy continuity within each streamtube. The turbine exit measured static pressure was assumed to vary linearly from hub to tip. The determination of the average turbine exit flow angle proceeded as follows:

$$\cos \Gamma_{avg} = \frac{\sum_{i=1}^{m} \rho_i V_i A_i \cos \Gamma_i}{\rho_{avg} V_{avg} A_{ann}}$$

where:
$$\rho_i V_i = P_{S_i} \sqrt{\frac{\gamma g}{R T_{T_i}}} \sqrt{\frac{2}{\gamma-1}\left[\left(\frac{P_T}{P_S}\right)_i^{\left(\frac{\gamma-1}{\gamma}\right)} - 1\right]} \Bigg/ \left(\frac{P_T}{P_S}\right)_i^{\frac{\gamma-1}{\gamma}}$$

P_T = Measured total pressure at center of i-th streamtube.

P_S = Static pressure at center of i-th streamtube based on linear variation in measured static pressure from hub to tip

T_T = Measured total temperature at center of i-th streamtube

Γ = Swirl angle

ρ = Density

V = Absolute velocity

A = Area

m = Number of streamtubes

i = Subscript denoting streamtube value

ann = Subscript denoting value for total annulus

avg = Subscript denoting average value for total annulus

The average velocity representing the turbine exit flow field was calculated by conserving the axial and tangential components of momentum, such that

$$V_{avg} = \left(V^2_{u_{avg}} + V^2_{z_{avg}}\right)^{1/2}$$

where $$V_{u_{avg}} = \left(\sum_{i=1}^{m} W_i\ V_i\ \sin \Gamma_i\right) \bigg/ \sum_{i=1}^{m} W_i$$

$$V_{z_{avg}} = \left(\sum_{i=1}^{m} W_i\ V_i\ \cos \Gamma_i\right) \bigg/ \sum_{i=1}^{m} W_i$$

and $$V_i = \sqrt{2g\ Jc_p\ T_{T_i}\left[1 - \left(\frac{P_S}{P_T}\right)_i^{\frac{\gamma-1}{\gamma}}\right]}$$

V_u = Tangential component of absolute velocity

V_z = Axial component of absolute velocity

W_i = Weight flow through i-th streamtube = $\rho_i V_i A_i \cos \Gamma_i$

The average turbine exit total temperature was determined through an energy balance of the annular streamtubes.

$$T_{T_{avg}} = \left(\sum_{i=1}^{m} W_i\ T_{T_i}\right) \bigg/ \sum_{i=1}^{m} W_i$$

The average density at the turbine exit was obtained from the equation of state.

$$\rho_{avg} = \frac{P_{S_{avg}}}{R\ T_{S_{avg}}}$$

where $$T_{S_{avg}} = T_{T_{avg}} - \frac{V^2_{avg}}{2g\ Jc_p}$$

Overall Performance - After obtaining the average turbine exit flow angle, the exit total pressure was calculated in the following manner:

$$P_{T_3} = P_{S_3} \left(1 + \frac{\gamma-1}{2} M_3^2\right)^{\gamma/\gamma-1}$$

Turbine exit Mach number, M_3, was determined from the following relationship:

$$\frac{W\sqrt{R\ T_{T_3}}}{P_S\ A_{ann}\ \cos\ \Gamma_{avg}} = \sqrt{\gamma g}\ \ M_3\sqrt{1 + \frac{\gamma-1}{2} M_3^2}$$

Turbine exit total temperature, T_{T_3}, was determined as follows:

$$T_{T_3} = T_{T_{oo}} - \frac{\Delta h}{c_p}$$

where $\Delta h = \dfrac{2\pi\ N\tau}{60\ J}$

N = Turbine rotative speed, rev/min

τ = Measured torque, ft-lbf

$T_{T_{oo}}$ = Measured turbine inlet total temperature, °R

W = Measured turbine weight flow, lbm/sec

Turbine inlet total pressure was calculated in the same manner as the turbine exit total pressure. The calculation used measured airflow, measured inlet total temperature, the average of measured hub and tip static pressures, and the assumption of zero inlet swirl angle.

The remaining parameters used in the overall performance calculation were obtained as follows:

$\delta = P_{T_o}/14.696$

$\theta_{cr} = T_{T_{oo}}/518.688$

$\varepsilon = 1.0$ (for $\gamma = 1.4$)

Equivalent Speed, N EQV = $N/\sqrt{\theta_{cr}}$

Equivalent Weight Flow, WA EQV = $W\sqrt{\theta_{cr}}\ \varepsilon/\delta$

Weight Flow-Speed Parameter, WAN EQV = $WN\varepsilon/60\delta$

Equivalent Torque, TQ EQV = $\tau\varepsilon/\delta$

Equivalent Specific Work, DH EQV = $\dfrac{E}{\theta_{cr}} = \dfrac{2\pi\ N\tau}{60\ J\ \theta_{cr}\ W}$

Ideal Equivalent Specific Work, DHI EQV =

$$\left(\frac{E}{\theta_{cr}}\right)_{ideal} = c_p\, T_{T_{oo}}\left[1-\left(\frac{P_{T_3}}{P_{T_o}}\right)^{\frac{\gamma-1}{\gamma}}\right]\theta_{cr}$$

Total-to-total Efficiency, ETA TT =

$$\eta_{TT} = \left(\frac{E}{\theta_{cr}}\right)\Big/\frac{E}{\theta_{cr}}_{\ ideal}$$

Blade-Jet Speed Ratio, U/CO =

$$\nu = \left\{\frac{KN^2}{c_p\ T_{T_{oo}}\left[1-\left(\frac{P_{S_3}}{P_{T_0}}\right)^{\frac{\gamma-1}{\gamma}}\right]}\right\}^{1/2}$$

where: $$K = \sum_{i=1}^{m}\left(\frac{\pi\ D_{p_i}}{720}\right)^2 \Big/ 2g\ J$$

where: m = number of turbine stages

D_p = pitchline diameter of the i-th rotor

APPENDIX B

STAGE EFFICIENCY CALCULATION

Calculations were performed to determine the efficiency of each stage of the various turbine configurations operating at the design point. In order to compare stage efficiencies on an equal basis, calculations were performed for a three-stage turbine total-to-total pressure ratio of 3.47. This is the pressure ratio at which the design equivalent specific work of 33.0 Btu/lbm is extracted when the three-stage plain blade turbine operates at design equivalent speed. The calculation procedure is outlined below:

1. Enter curves of equivalent specific work versus total-to-total pressure ratio at design equivalent speed for the three-stage turbines to obtain equivalent specific work at a pressure ratio of 3.47.

2. Enter three-stage turbine curves of normalized static pressure versus total-to-total pressure ratio at a pressure ratio of 3.47 to determine normalized static pressures at the hub and tip of Stage One and Stage Two exits.

3. At the Stage One and Stage Two normalized hub and tip exit static pressures, enter curves of normalized static pressure versus total-to-total pressure ratios across the one-stage and two-stage turbines.

4. Enter curves of equivalent specific work versus total-to-total pressure ratio for the one-stage and two-stage turbines to determine their equivalent specific works.

5. Using the above information and Keenan and Kaye's <u>Gas Tables</u> (Reference 7), calculate the stage efficiencies.

An example, showing the stage efficiency calculations for the plain blade turbine, is presented below.

1. At $P_{T_0}/P_{T_3} = 3.47$, $(E/\theta_{cr}) = 33.0$ Btu/lbm

2. At Stage One exit, $P_S/P_{T_0} = 0.494$

   At Stage Two exit, $P_S/P_{T_0} = 0.300$

3. For the one-stage turbine, $P_{T_0}/P_{T_{1.3}} = 1.604$

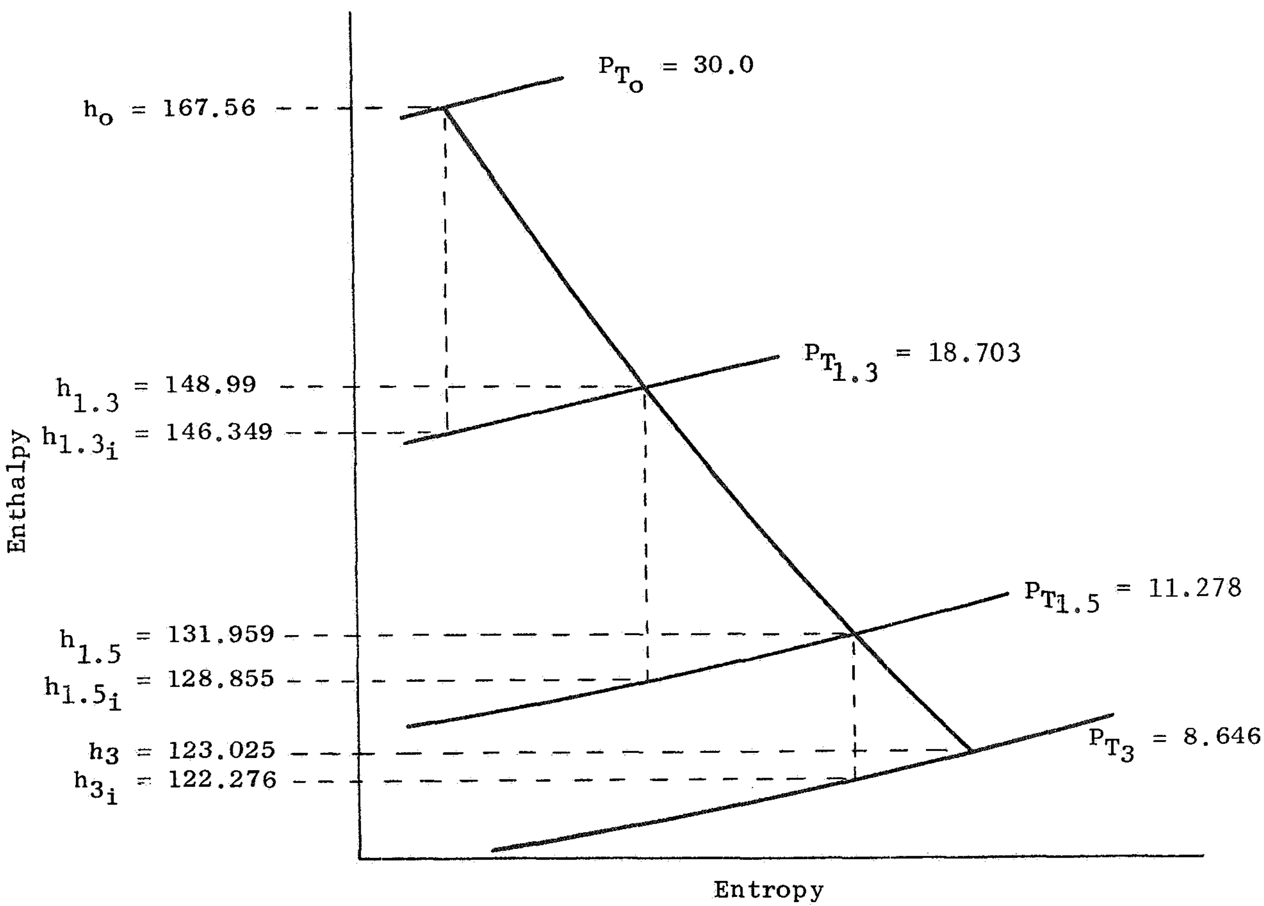
   For the two-stage turbine, $P_{T_0}/P_{T_{1.5}} = 2.66$

4. For the one-stage turbine, $E/\theta_{cr} = 13.76$

   For the two-stage turbine, $E/\theta_{cr} = 26.38$

5. Stage efficiencies are calculated from the above information and the accompanying sketch which was constructed using Table I of Reference 7.

	E/θ_{cr}	Δh
Stage One	13.76	18.570
Stage Two	12.62	17.031
Stage Three	6.62	8.934
Total	33.00	44.535



Stage One

$$\eta_{TT} = \frac{h_o - h_{1.3}}{h_o - h_{1.3_i}} = \frac{167.560 - 148.990}{167.560 - 146.349} = 0.875$$

Stage Two

$$\eta_{TT} = \frac{h_{1.3} - h_{1.5}}{h_{1.3} - h_{1.5_i}} = \frac{148.990 - 131.959}{148.990 - 128.855} = 0.846$$

Stage Three

$$\eta_{TT} = \frac{h_{1.5} - h_3}{h_{1.5} - h_{3_i}} = \frac{131.959 - 123.025}{131.959 - 122.276} = 0.923$$

APPENDIX C

REYNOLDS NUMBER CALCULATION

The turbine Reynolds numbers were based on the energy weighted Reynolds numbers of each blade row as defined below:

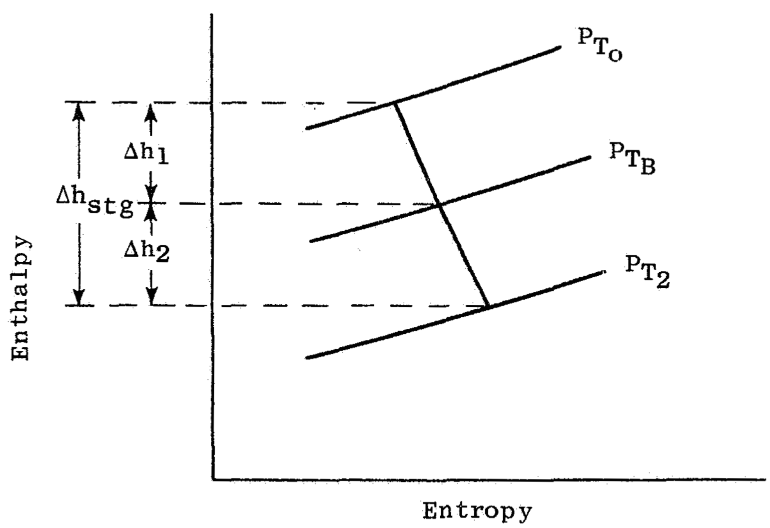
$$\bar{R}_N = \left(\sum_{i=1}^{m} \Delta h_i \, R_{N_i} \right) \Bigg/ \sum_{i=1}^{m} \Delta h_i$$

where

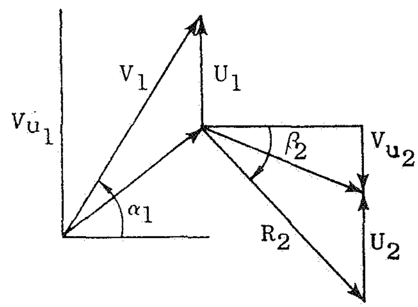
$$R_{N_i} = \left(\frac{12 \; W \; \ell}{\mu \; n d_o \; h} \right)_i$$

and Δh_i = Equivalent fractional energy extraction of i-th bladerow.

The equivalent fractional energy extraction of each bladerow is derived as follows. The velocity diagram energy for each stage can be divided into two constituents associated with the stator and rotor leaving energies. This division of the total stage energy is illustrated on the following enthalpy-entropy diagram:



The energies Δh_1 and Δh_2 can be expressed in terms of the stage velocity diagram parameters as shown below:



From the sketches,

$$\Delta h_{stg} = \frac{1}{gJ} \left(U_1 V_{u_1} + U_2 V_{u_2}\right)$$

$$\Delta h_{stg} = \frac{1}{gJ} \left(U_1 V_1 \sin \alpha_1 + U_2 R_2 \sin \beta_2 - U_2^{\,2}\right)$$

With the appropriate combination of terms and algebraic manipulations the above expressions can be simply expressed as:

$$\Delta h_{stg} = \Delta h_1 + \Delta h_2 + \frac{U_1^{\,2} - U_2^{\,2}}{2gJ}$$

where

$$\Delta h_1 = \frac{V_1^{\,2}}{2gJ} \left[\left(\frac{U_1}{V_1}\right)\left(2 \sin \alpha_1 - \frac{U_1}{V_1}\right)\right]$$

and

$$\Delta h_2 = \frac{R_2^{\,2}}{2gJ} \left[\left(\frac{U_2}{R_2}\right)\left(2 \sin \beta_2 - \frac{U_2}{R_2}\right)\right]$$

The terms $\frac{V_1^{\,2}}{2gJ}$ and $\frac{R_2^{\,2}}{2gJ}$ are the energy equivalents of velocity leaving the stator and rotor respectively.

The terms $\left[\left(\frac{U_1}{V_1}\right)\left(2 \sin \alpha_1 - \frac{U_1}{V_1}\right)\right]$ and $\left[\left(\frac{U_2}{R_2}\right)\left(2 \sin \beta_2 - \frac{U_2}{R_2}\right)\right]$ are properties of the velocity diagrams at the stator and rotor exit planes.

APPENDIX D

LIST OF SYMBOLS

A	Area (in.^{2})
c_p	Specific heat at constant pressure (ft^2/sec^2 °R)
D	Diameter (in.)
d_o	Bladerow throat dimension (in.)
Hi-C	Maximum distance from axis of least moment of inertia, blade suction (convex) surface
Δh	Turbine energy extraction (Btu/lbm)
Δh_{stg}	Stage energy extraction (Btu/lbm)
h_{ex}	Height of bladerow at exit (in.)
h_{th}	Height of bladerow at throat (in.)
L	Tangentially leaned bladerow
ℓ	Blade or vane suction surface length (in.)
M	Mach number
m	Number of bladerows, streamtubes, or stages
N	Rotational speed (rev/min)
n	Number of vanes or blades
P	Plain bladerow
P_S	Static pressure (psia)
P_{S_3}	Turbine exit static pressure
P_T	Total pressure (psia)
P_{T_o}	Turbine inlet total pressure
P_{T_3}	Turbine exit total pressure
R	Gas constant (ft^2/sec^2 °R)
R_2	Rotor exit relative gas velocity
R_N	Reynolds number
$\overline{R_N}$	Energy weighted overall Reynolds number

T	Tandem bladerow
T_S	Static temperature (°R)
T_T	Total temperature (°R)
$T_{T\,oo}$	Turbine inlet total temperature
$T_{T\,3}$	Turbine exit total temperature
t	Spacing (in.)
U	Wheel speed (ft/sec)
V	Absolute velocity (ft/sec)
W	Mass flow rate (lbm/sec)
E/θ_{cr}	Equivalent specific work (Btu/lbm)
$W\sqrt{\theta_{cr}}\,\varepsilon/\delta$	Equivalent weight flow (lbm/sec)
$N/\sqrt{\theta_{cr}}$	Equivalent rotative speed (rev/min)
$WN\varepsilon/60\delta$	Weight flow - speed parameter (lbm/sec^2)
$gJ\Delta h/2U^2$	Loading factor
α_o	Vane inlet absolute flow angle (degrees)
α_1	Vane exit absolute flow angle (degrees)
β_1	Blade inlet relative flow angle (degrees)
β_2	Blade exit relative flow angle (degrees)
Γ	Stage leaving swirl angle (degrees)
γ	Specific heat ratio
δ	Ratio of turbine pressure to pressure at standard sea level conditions
ε	Function of γ defined as $\dfrac{\gamma_{SL}}{\gamma}\left[\left(\dfrac{\gamma+1}{2}\right)^{\gamma/\gamma-1}\Big/\left(\dfrac{\gamma_{SL}+1}{2}\right)^{\gamma_{SL}/\gamma_{SL}-1}\right]$
η_{TT}	Total-to-total efficiency

η_{TS} Total-to-static efficiency

θ_{cr} Squared ratio of critical velocity at turbine inlet temperature to critical velocity at standard sea level temperature

μ Viscosity (lbm/sec-ft)

ν Blade-jet speed ratio

ρ Density (lbm/ft^3)

τ Torque (ft-lbf)

τ_{eq} Equivalent torque (ft-lbf), $\tau_{eq} = \tau\varepsilon/\delta$

Subscripts

B Relative to rotor blade

h Hub

i Current axial station, stage, streamtube, or ideal

p Pitch

R Relative

r Radial component

t Tip

u Tangential component

z Axial component

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Table I. Reduced Test Data and Calculated Performance Parameters - Configuration 1 (PPPPPP).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
1	100	29.91	3.490	3.843	3168.93	27.993	1478.45	2174.65	33.130	37.385	0.8862	0.3702	7.96
2	100	29.92	3.480	3.831	3167.52	28.021	1479.27	2171.83	33.039	37.313	0.8854	0.3704	8.26
3	100	29.92	3.474	3.823	3165.96	28.005	1477.73	2172.64	33.053	37.270	0.8869	0.3705	8.49
4	120	29.96	3.482	3.829	3794.75	27.492	1738.77	1785.83	33.172	37.323	0.8888	0.4439	12.65
5	120	29.97	3.486	3.833	3795.14	27.488	1738.70	1785.31	33.171	37.355	0.8880	0.4437	12.37
6	120	29.99	3.484	3.831	3797.23	27.491	1739.82	1783.18	33.146	37.342	0.8876	0.4441	12.35
7	110	29.96	3.485	3.831	3482.08	27.822	1614.63	1979.60	33.342	37.347	0.8928	0.4072	8.66
8	110	29.97	3.485	3.831	3479.59	27.823	1613.57	1980.39	33.329	37.345	0.8925	0.4069	8.50
9	110	29.97	3.487	3.832	3481.78	27.814	1614.02	1978.15	33.324	37.359	0.8920	0.4071	8.14
10	91	29.92	3.412	3.755	2889.59	28.097	1353.17	2328.76	32.229	36.819	0.8753	0.3400	11.82
11	91	29.88	3.444	3.791	2896.42	28.080	1355.52	2324.40	32.265	37.053	0.8708	0.3398	9.37
12	92	29.80	3.455	3.805	2900.56	28.094	1358.15	2324.56	32.297	37.129	0.8699	0.3399	9.16
13	100	29.90	3.449	3.790	3166.10	28.023	1478.73	2165.61	32.927	37.091	0.8877	0.3715	7.86
14	100	29.85	3.443	3.782	3162.64	28.040	1478.02	2162.08	32.817	37.045	0.8859	0.3713	7.77
15	100	29.85	3.463	3.809	3164.32	28.023	1477.90	2167.33	32.934	37.193	0.8855	0.3707	7.84
16	85	29.91	3.456	3.818	2692.47	28.117	1261.75	2446.61	31.528	37.142	0.8489	0.3152	11.54
17	85	29.92	3.453	3.814	2691.61	28.116	1261.27	2445.21	31.502	37.119	0.8487	0.3152	11.54
18	85	29.92	3.447	3.805	2690.63	28.122	1261.11	2443.27	31.458	37.072	0.8486	0.3153	11.48
19	100	29.91	3.476	3.826	3166.26	28.035	1479.43	2171.97	33.011	37.285	0.8854	0.3704	8.02
20	100	29.90	3.479	3.830	3167.13	28.038	1479.99	2172.04	33.018	37.305	0.8851	0.3704	7.92
21	100	29.91	3.480	3.831	3163.72	28.030	1477.99	2172.93	33.005	37.314	0.8845	0.3700	7.94
22	90	29.91	3.652	4.081	2846.19	28.122	1334.02	2434.32	33.155	38.507	0.8610	0.3267	11.18
23	90	29.91	3.656	4.085	2847.64	28.110	1334.14	2433.64	33.177	38.531	0.8610	0.3267	11.20
24	90	29.91	3.657	4.087	2847.17	28.109	1333.85	2433.70	33.174	38.540	0.8608	0.326	11.19
25	100	29.87	3.662	4.078	3170.83	28.043	1482.00	2241.91	34.113	38.575	0.8843	0.3640	8.58
26	100	29.86	3.663	4.078	3163.82	28.047	1478.91	2247.97	34.125	38.578	0.8846	0.3632	8.50
27	100	29.87	3.658	4.071	3161.38	28.041	1477.48	2245.06	34.062	38.544	0.8837	0.3631	8.20
28	110	29.92	3.684	4.096	3483.46	27.827	1615.56	2052.81	34.582	38.719	0.8932	0.3994	8.25
29	110	29.92	3.682	4.093	3483.24	27.826	1615.41	2051.67	34.562	38.708	0.8929	0.3995	7.69
30	110	29.92	3.681	4.092	3485.94	27.824	1616.54	2050.01	34.563	38.703	0.8930	0.3998	7.97
31	120	29.93	3.672	4.075	3795.12	27.512	1740.21	1856.70	34.467	38.638	0.8920	0.4358	10.37
32	120	29.92	3.678	4.083	3795.97	27.514	1740.67	1856.26	34.465	38.682	0.8910	0.4356	10.16
33	120	29.91	3.681	4.086	3795.61	27.513	1740.49	1858.07	34.496	38.702	0.8913	0.4355	9.78
34	120	29.88	3.895	4.380	3796.35	27.554	1743.38	1931.02	35.804	40.076	0.8934	0.4272	8.86
35	120	29.88	3.896	4.379	3796.31	27.552	1743.28	1929.78	35.783	40.080	0.8928	0.4272	8.48
36	120	29.89	3.902	4.387	3797.16	27.539	1742.86	1929.71	35.806	40.115	0.8926	0.4271	8.6
37	110	29.88	3.889	4.380	3480.53	27.852	1615.63	2126.92	35.769	40.039	0.8934	0.3916	7.37
38	110	29.88	3.890	4.382	3483.32	27.842	1616.38	2124.23	35.765	40.043	0.8931	0.3919	7.81
39	110	29.89	3.891	4.383	3479.35	27.837	1614.25	2126.37	35.766	40.046	0.8931	0.3914	7.95
40	100	29.88	3.873	4.377	3163.21	27.958	1473.97	2325.51	35.407	39.939	0.8865	0.3560	10.87
41	100	29.89	3.879	4.387	3161.60	28.026	1476.79	2321.81	35.248	39.974	0.8818	0.3556	10.19
42	100	29.88	3.882	4.392	3161.45	28.019	1476.34	2324.91	35.302	39.993	0.8827	0.3555	10.47
43	90	29.89	3.851	4.380	2842.62	28.087	1330.67	2509.91	34.185	39.802	0.8589	0.3198	14.66
44	90	29.87	3.850	4.379	2841.58	28.107	1331.15	2509.87	34.147	39.793	0.8581	0.3198	14.50
45	90	29.88	3.856	4.388	2842.96	28.097	1331.29	2510.25	34.182	39.834	0.8581	0.3197	14.56
46	100	29.89	3.472	3.819	3157.79	28.020	1474.68	2178.53	33.040	37.254	0.8869	0.3696	7.73
47	100	29.89	3.470	3.818	3158.46	28.013	1474.64	2175.77	33.013	37.242	0.8864	0.3698	8.17
48	100	29.88	3.469	3.817	3157.75	28.022	1474.77	2176.65	33.009	37.237	0.8865	0.3697	8.27
49	90	29.87	3.131	3.386	2844.75	28.096	1332.09	2214.65	30.176	34.637	0.8712	0.3462	8.40
50	90	29.87	3.133	3.391	2844.66	28.099	1332.23	2213.60	30.157	34.660	0.8701	0.3461	8.61

Table I. Reduced Test Data and Calculated Performance Parameters - Configuration 1 (PPPPPP) (Continued).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
51	90	29.88	3.133	3.389	2845.79	28.092	1332.38	2211.47	30.149	34.655	0.8700	0.3463	8.32
52	100	29.86	3.127	3.379	3155.90	27.978	1471.59	2033.74	30.872	34.608	0.8921	0.3644	9.52
53	100	29.88	3.134	3.387	3157.36	27.995	1473.19	2029.95	30.809	34.665	0.8888	0.3842	8.6
54	100	29.87	3.137	3.390	3155.89	28.001	1472.82	2032.87	30.833	34.686	0.8889	0.3839	8.61
55	110	29.91	3.137	3.392	3477.94	27.757	1608.96	1833.97	30.924	34.691	0.8914	0.4231	11.98
56	110	29.90	3.137	3.391	3478.20	27.760	1609.25	1833.99	30.924	34.686	0.8915	0.4231	11.79
57	110	29.90	3.134	3.388	3478.03	27.769	1609.68	1834.67	30.924	34.669	0.8920	0.4232	11.81
58	120	29.91	3.124	3.385	3794.99	27.391	1732.50	1640.05	30.578	34.579	0.8843	0.4620	17.96
59	120	29.90	3.121	3.381	3796.00	27.402	1733.61	1639.94	30.573	34.557	0.8847	0.4622	17.95
60	120	29.90	3.121	3.382	3794.40	27.406	1733.16	1641.23	30.579	34.559	0.8848	0.4620	17.97
61	80	29.89	2.795	2.979	2544.69	28.118	1192.54	2203.62	26.837	31.681	0.8471	0.3246	8.86
62	80	29.89	2.797	2.981	2544.70	28.114	1192.35	2203.99	26.847	31.694	0.8470	0.3245	9.10
63	80	29.90	2.794	2.978	2544.79	28.118	1192.57	2202.41	26.824	31.672	0.8469	0.3246	8.92
64	90	29.89	2.801	2.983	2839.59	28.063	1328.10	2039.81	27.776	31.736	0.8752	0.3620	8.46
65	90	29.88	2.799	2.981	2839.97	28.069	1328.59	2038.65	27.758	31.720	0.8751	0.3621	8.66
66	90	29.89	2.798	2.979	2842.21	28.064	1329.39	2036.91	27.761	31.708	0.8755	0.3625	8.70
67	100	29.91	2.798	2.983	3156.89	27.925	1469.26	1856.50	28.244	31.711	0.8907	0.4024	13.49
68	100	29.91	2.798	2.983	3163.14	27.923	1472.09	1852.58	28.241	31.710	0.8906	0.4032	13.41
69	100	29.91	2.798	2.983	3161.44	27.927	1471.49	1854.82	28.257	31.709	0.8911	0.4030	13.43
70	110	29.91	2.794	2.985	3476.55	27.607	1599.60	1659.39	28.122	31.666	0.8881	0.4431	19.13
71	110	29.92	2.795	2.987	3476.13	27.610	1599.62	1661.42	28.149	31.676	0.8886	0.4429	19.02
72	110	29.91	2.791	2.982	3475.30	27.614	1599.45	1659.26	28.102	31.642	0.8881	0.4431	19.11
73	120	29.92	2.787	2.989	3791.47	27.193	1718.34	1478.91	27.750	31.600	0.8782	0.4829	24.86
74	120	29.91	2.787	2.990	3792.44	27.193	1718.79	1478.06	27.741	31.606	0.8777	0.4830	24.8
75	120	29.92	2.786	2.989	3792.69	27.192	1718.82	1477.74	27.738	31.597	0.8778	0.4831	24.85
76	100	29.91	3.477	3.826	3158.49	28.013	1474.65	2180.09	33.079	37.288	0.8871	0.3695	8.22
77	100	29.91	3.484	3.8 5	3157.90	28.018	1474.63	2183.33	33.116	37.339	0.8869	0.3692	8.01
78	100	29.92	3.485	3.836	3159.71	28.007	1474.92	2181.28	33.117	37.346	0.8867	0.3694	7.86
79	100	19.99	3.468	3.813	3166.48	27.955	1475.32	2159.61	32.919	37.224	0.8844	0.3708	8.09
80	100	19.99	3.472	3.820	3164.17	27.962	1474.60	2162.63	32.933	37.258	0.8839	0.3704	8.48
81	100	19.99	3.472	3.820	3164.55	27.961	1474.72	2159.82	32.896	37.257	0.8829	0.3704	8.19
82	119	19.98	3.465	3.805	3786.77	27.421	1730.59	1774.83	32.984	37.208	0.8865	0.4436	12.55
83	119	20.00	3.471	3.812	3783.83	27.406	1728.34	1776.14	33.001	37.250	0.8859	0.4432	12.24
84	119	20.00	3.472	3.812	3785.97	27.404	1729.18	1775.17	33.004	37.255	0.8859	0.4434	12.19
85	110	19.99	3.486	3.831	3483.85	27.719	1609.47	1961.83	33.182	37.352	0.8884	0.4074	9.04
86	110	19.99	3.486	3.830	3483.02	27.732	1609.85	1961.25	33.149	37.354	0.8874	0.4074	8.31
87	110	19.99	3.485	3.829	3482.70	27.731	1609.66	1963.32	33.181	37.348	0.8884	0.4074	8.45
88	90	20.00	3.463	3.818	2849.73	28.037	1331.61	2346.28	32.094	37.189	0.8630	0.3336	10.32
89	90	19.98	3.467	3.826	2850.54	28.063	1333.23	2342.76	32.025	37.222	0.8604	0.3335	10.37
90	90	19.99	3.473	3.831	2850.93	28.049	1332.76	2348.04	32.117	37.260	0.8620	0.3334	10.02
91	80	19.97	3.446	3.816	2531.20	28.077	1184.48	2524.94	30.633	37.069	0.8264	0.2964	13.82
92	80	19.96	3.443	3.811	2531.00	28.086	1184.76	2525.34	30.625	37.042	0.8268	0.2965	13.88
94	72	19.97	3.426	3.819	2282.33	28.091	1068.55	2660.83	29.093	36.926	0.7879	0.2672	18.38
95	72	19.97	3.427	3.819	2282.79	28.091	1068.75	2662.37	29.116	36.932	0.7884	0.2672	18.28
96	72	19.97	3.424	3.815	2282.37	28.103	1069.00	2662.29	29.097	36.906	0.7884	0.2673	18.35
97	80	19.97	3.643	4.103	2537.24	28.078	1187.34	2598.28	31.597	38.448	0.8218	0.2908	16.54
98	80	19.97	3.647	4.108	2537.19	28.067	1186.84	2600.14	31.631	38.473	0.8222	0.2906	16.68
99	80	19.97	3.647	4.108	2535.13	28.082	1186.54	2600.91	31.597	38.469	0.8214	0.2904	16.59
103	80	19.97	3.126	3.389	2535.05	28.087	1186.71	2375.66	28.855	34.600	0.8340	0.3084	10.82
104	80	19.97	3.126	3.389	2534.05	28.085	1186.13	2375.20	28.841	34.596	0.8336	0.3083	11.23

Table I. Reduced Test Data and Calculated Performance Parameters - Configuration 1 (PPPPPP) (Continued).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
105	80	19.96	3.125	3.389	2534.83	28.092	1186.82	2374.28	28.831	34.593	0.8334	0.3084	11.16
106	71	19.97	3.110	3.389	2236.88	28.103	1047.73	2545.50	27.266	34.466	0.7911	0.2722	16.22
107	71	19.97	3.110	3.389	2236.62	28.099	1047.46	2544.28	27.253	34.469	0.7907	0.2721	16.16
108	71	19.98	3.109	3.387	2236.46	28.087	1046.94	2543.31	27.253	34.462	0.7908	0.2722	16.18
109	100	19.97	3.461	3.807	3166.81	27.947	1475.02	2150.78	32.798	37.178	0.8822	0.3711	8.03
110	100	19.97	3.473	3.820	3162.87	27.956	1473.68	2154.72	32.806	37.260	0.8805	0.3702	8.20
111	100	19.97	3.476	3.824	3165.36	27.954	1474.76	2155.65	32.848	37.281	0.8811	0.3704	8.28
112	100	29.83	3.464	3.810	3161.59	28.002	1475.50	2175.15	33.050	37.195	0.8886	0.3704	8.83
113	100	29.83	3.475	3.824	3159.22	28.011	1474.86	2175.83	33.025	37.276	0.8860	0.3697	8.10
114	100	29.84	3.477	3.827	3160.56	28.013	1475.59	2175.83	33.037	37.292	0.8859	0.3697	8.04
115	120	29.87	2.447	2.601	3798.67	26.800	1696.74	1271.86	24.260	28.090	0.8636	0.5130	31.5
116	120	29.89	2.451	2.600	3800.06	26.797	1697.17	1270.42	24.244	28.132	0.8618	0.5127	31.70
117	120	29.89	2.449	2.603	3797.93	26.801	1696.47	1270.41	24.227	28.105	0.8620	0.5127	31.70
118	110	29.89	2.451	2.590	3478.19	27.263	1580.45	1437.65	24.682	28.133	0.8773	0.4706	25.10
119	110	29.89	2.450	2.590	3477.65	27.265	1580.32	1436.68	24.660	28.124	0.8768	0.4706	25.10
120	110	29.88	2.451	2.590	3478.66	27.266	1580.81	1437.25	24.677	28.129	0.8773	0.4707	25.24
121	100	29.94	2.458	2.590	3159.82	27.723	1459.99	1631.78	25.029	28.209	0.8873	0.4275	19.35
122	100	29.95	2.458	2.591	3161.30	27.721	1460.58	1630.00	25.015	28.207	0.8868	0.4277	19.54
123	100	29.94	2.457	2.590	3162.19	27.727	1461.28	1631.15	25.035	28.197	0.8878	0.4279	19.57
124	90	29.95	2.460	2.587	2846.90	27.991	1328.11	1816.91	24.869	28.233	0.8808	0.3854	13.16
125	90	29.94	2.459	2.586	2845.26	27.997	1327.63	1817.12	24.852	28.219	0.8807	0.385	13.25
126	90	29.95	2.464	2.591	2845.10	27.977	1326.64	1818.85	24.891	28.272	0.8804	0.3849	13.18
127	80	29.95	2.465	2.590	2532.72	28.074	1185.06	1992.78	24.194	28.281	0.8555	0.3427	9.24
128	80	29.95	2.464	2.589	2531.60	28.079	1184.77	1992.47	24.174	28.275	0.8550	0.3426	9.21
129	80	29.95	2.462	2.587	2530.65	28.090	1184.74	1992.29	24.155	28.250	0.8550	0.3426	9.20
130	80	29.93	2.111	2.193	2533.48	27.956	1180.43	1702.11	20.758	23.931	0.8674	0.3731	14.22
131	80	29.93	2.112	2.193	2531.93	27.954	1179.64	1711.27	20.858	23.937	0.8714	0.3728	14.19
132	80	29.93	2.110	2.192	2533.83	27.950	1180.36	1708.69	20.845	23.921	0.8714	0.3733	14.19
133	90	29.94	2.109	2.196	2848.29	27.602	1310.29	1522.16	21.138	23.901	0.8844	0.4192	21.78
134	90	29.94	2.110	2.196	2850.07	27.604	1311.23	1521.72	21.143	23.916	0.8841	0.4194	21.38
135	90	29.93	2.110	2.196	2848.46	27.608	1310.68	1522.54	21.140	23.913	0.8840	0.4192	21.37
136	100	29.93	2.102	2.196	3166.03	27.075	1428.69	1327.46	20.889	23.809	0.8774	0.4659	28.82
137	100	29.93	2.103	2.197	3167.48	27.071	1429.14	1326.59	20.888	23.823	0.8768	0.4660	28.88
138	100	29.93	2.104	2.198	3165.63	27.070	1428.23	1325.53	20.860	23.828	0.8755	0.4656	28.89
139	110	29.92	2.093	2.198	3485.79	26.460	1537.22	1144.89	20.297	23.686	0.8569	0.5127	35.62
140	110	29.91	2.092	2.196	3484.08	26.469	1536.97	1144.65	20.276	23.671	0.8566	0.5127	35.63
141	110	29.92	2.092	2.196	3482.90	26.461	1535.99	1144.23	20.268	23.669	0.8563	0.5125	35.70
142	120	29.91	2.077	2.197	3795.33	25.922	1639.68	989.51	19.497	23.461	0.8310	0.5584	41.99
143	120	29.92	2.078	2.198	3796.76	25.920	1640.18	989.39	19.503	23.477	0.8307	0.5584	41.99
144	120	29.93	2.079	2.199	3796.08	25.906	1639.02	989.83	19.519	23.491	0.8309	0.5582	41.96
145	100	34.89	3.477	3.827	3164.82	28.022	1478.06	2180.93	33.148	37.290	0.8889	0.3702	8.29
146	100	34.90	3.489	3.842	3162.80	28.009	1476.45	2183.87	33.186	37.376	0.8879	0.3696	8.16
147	100	34.87	3.494	3.849	3161.84	28.018	1476.48	2188.07	33.229	37.415	0.8881	0.3692	7.90
148	110	34.94	3.476	3.819	3475.71	27.839	1612.70	1988.25	33.405	37.282	0.8960	0.4069	8.71
149	110	34.93	3.480	3.825	3477.13	27.844	1613.61	1989.67	33.437	37.314	0.8961	0.4068	8.56
150	110	34.93	3.480	3.825	3476.05	27.846	1613.22	1987.21	33.384	37.311	0.8947	0.4067	8.51
151	92	34.94	3.465	3.821	2911.47	28.087	1362.90	2328.35	32.480	37.204	0.8730	0.3408	10.33
152	92	34.94	3.467	3.822	2911.00	28.082	1362.42	2328.19	32.479	37.216	0.8727	0.3407	10.07
153	92	34.94	3.467	3.823	2911.31	28.086	1362.76	2328.11	32.476	37.217	0.8726	0.3407	10.10
154	100	39.90	3.478	3.828	3163.13	28.042	1478.37	2184.57	33.161	37.296	0.8891	0.3700	8.23

Table I. Reduced Test Data and Calculated Performance Parameters - Configuration 1 (PPPPPP) (Concluded).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
155	100	39.89	3.479	3.829	3162.51	28.036	1477.75	2185.13	33.170	37.302	0.8892	0.3699	8.09
156	100	39.90	3.481	3.831	3162.36	28.036	1477.69	2184.24	33.155	37.317	0.8885	0.3698	7.02
157	110	39.92	3.480	3.825	3474.58	27.862	1613.49	1995.05	33.481	37.314	0.8973	0.4065	8.61
158	110	39.91	3.480	3.825	3473.57	27.868	1613.34	1994.93	33.463	37.312	0.8968	0.4064	8.54
159	110	39.91	3.481	3.826	3473.04	27.863	1612.82	1995.69	33.476	37.319	0.8970	0.4063	8.57
160	70	19.95	2.800	2.993	2215.29	28.080	1036.76	2382.62	25.295	31.725	0.7973	0.2820	12.85
161	70	19.95	2.799	2.991	2214.98	28.084	1036.75	2380.93	25.271	31.715	0.7968	0.2821	12.96
162	70	19.94	2.796	2.987	2214.27	28.095	1036.82	2381.76	25.262	31.685	0.7973	0.2821	12.98
163	70	19.95	2.466	2.595	2217.99	28.069	1037.62	2157.48	22.942	28.303	0.8106	0.2999	10.00
164	70	19.95	2.469	2.596	2218.52	28.082	1038.33	2158.49	22.948	28.326	0.8102	0.2999	9.12
165	70	19.95	2.465	2.593	2217.56	28.082	1037.91	2158.37	22.937	28.290	0.8108	0.2999	9.6
166	70	19.92	2.107	2.187	2211.02	28.045	1033.48	1874.99	19.893	23.881	0.8330	0.3261	9.83
167	70	19.93	2.108	2.188	2209.07	28.036	1032.21	1875.36	19.886	23.894	0.8322	0.3257	9.46
168	70	19.93	2.106	2.180	2207.03	28.042	1031.49	1874.46	19.853	23.864	0.8320	0.3256	9.47
169	100	29.91	3.469	3.816	3161.33	28.004	1475.48	2174.60	33.036	37.233	0.8873	0.3702	8.20
170	100	29.91	3.473	3.821	3159.25	28.012	1474.96	2177.87	33.054	37.263	0.8870	0.3697	8.11
171	100	29.91	3.474	3.823	3160.17	28.010	1475.30	2177.09	33.054	37.272	0.8868	0.3698	8.12
172	80	29.91	1.724	1.771	2529.12	26.635	1122.73	1234.64	15.777	17.934	0.8797	0.4301	25.12
173	80	29.91	1.724	1.771	2524.96	26.634	1120.83	1236.41	15.774	17.933	0.8796	0.4294	25.17
174	80	29.91	1.723	1.771	2524.66	26.627	1120.39	1235.37	15.763	17.924	0.8795	0.4295	25.20
175	90	29.91	1.715	1.769	2844.05	25.810	1223.42	1040.73	15.433	17.780	0.8680	0.4842	34.79
176	90	29.92	1.715	1.769	2842.00	25.805	1222.28	1041.09	15.430	17.780	0.8678	0.4838	34.81
177	90	29.91	1.715	1.769	2842.37	25.820	1223.17	1042.20	15.440	17.772	0.8688	0.4840	34.82
178	100	29.91	1.700	1.760	3164.13	25.010	1318.94	866.31	14.749	17.517	0.8420	0.5395	43.91
179	100	29.90	1.700	1.766	3159.87	25.009	1317.10	867.93	14.758	17.518	0.8424	0.5387	43.92
180	100	29.92	1.701	1.767	3161.30	24.998	1317.12	867.51	14.764	17.537	0.8419	0.5387	43.9
181	110	29.90	1.687	1.763	3477.21	24.317	1409.29	721.91	13.892	17.271	0.8043	0.5936	49.68
182	110	29.92	1.688	1.764	3479.38	24.315	1410.00	721.93	13.902	17.293	0.8039	0.5936	49.67
183	110	29.91	1.687	1.764	3479.54	24.316	1410.14	721.67	13.897	17.280	0.8042	0.5938	49.69
184	115	29.94	1.683	1.768	3648.30	24.030	1461.14	661.48	13.515	17.208	0.7854	0.6214	52.41
185	115	29.95	1.686	1.771	3646.65	24.043	1461.25	661.96	13.511	17.253	0.7832	0.6204	52.34
186	115	29.94	1.686	1.771	3644.79	24.050	1460.96	662.94	13.520	17.254	0.7836	0.6201	52.31

Table II. Reduced Test Data and Calculated Performance Parameters - Configuration 2 (PPPP).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
187	100	29.83	2.756	3.370	3167.05	28.032	1479.64	1774.63	26.982	31.309	0.8618	0.3067	42.13
188	100	29.84	2.755	3.367	3153.76	28.033	1473.47	1778.97	26.933	31.293	0.8607	0.3055	42.14
189	99	29.84	2.760	3.377	3147.06	28.030	1470.22	1782.65	26.934	31.343	0.8593	0.3046	42.13
190	120	29.88	2.849	3.367	3795.84	27.554	1743.21	1516.93	28.122	32.184	0.8738	0.3677	36.88
191	120	29.88	2.849	3.368	3793.86	27.558	1742.52	1516.23	28.090	32.187	0.8727	0.3675	36.88
192	120	29.90	2.851	3.370	3793.72	27.552	1742.07	1516.70	28.104	32.203	0.8727	0.3674	36.88
193	110	29.89	2.805	3.374	3486.35	27.837	1617.48	1645.11	27.727	31.771	0.8727	0.3375	39.78
194	110	29.88	2.805	3.375	3482.14	27.838	1615.62	1646.47	27.715	31.775	0.8722	0.3370	39.78
195	110	29.88	2.805	3.376	3481.94	27.839	1615.55	1646.66	27.716	31.778	0.8722	0.3370	39.79
196	90	29.89	2.695	3.373	2851.47	28.095	1335.21	1893.49	25.862	30.703	0.8423	0.2761	45.26
197	90	29.89	2.694	3.373	2847.81	28.111	1334.24	1894.87	25.833	30.692	0.8417	0.2757	45.25
198	90	29.89	2.693	3.371	2845.24	28.111	1333.05	1895.01	25.811	30.684	0.8412	0.2755	45.25
199	80	29.88	2.628	3.367	2529.47	28.148	1186.66	2009.63	24.303	30.034	0.8092	0.2450	47.75
200	80	29.89	2.627	3.364	2529.48	28.140	1186.33	2008.97	24.302	30.024	0.8094	0.2451	47.75
201	80	29.88	2.625	3.361	2530.36	28.148	1187.06	2007.77	24.289	30.003	0.8095	0.2453	47.7
202	100	29.89	2.737	3.365	3153.39	28.042	1473.79	1779.07	26.923	31.117	0.8652	0.3055	43.14
203	100	29.89	2.740	3.372	3156.04	28.043	1475.11	1779.33	26.948	31.152	0.8650	0.3056	43.14
204	100	29.88	2.741	3.373	3164.43	28.041	1478.89	1777.06	26.988	31.161	0.8661	0.3064	43.13
205	100	29.86	2.513	2.887	3165.55	28.019	1478.25	1652.48	25.124	28.812	0.8720	0.3248	38.59
206	100	29.87	2.514	2.889	3166.09	28.014	1478.25	1651.72	25.121	28.828	0.8714	0.3247	38.57
207	100	29.86	2.516	2.891	3169.22	28.011	1479.56	1652.50	25.161	28.842	0.8724	0.3250	38.59
208	90	29.88	2.482	2.895	2851.55	28.108	1335.84	1774.64	24.228	28.474	0.8509	0.2922	41.62
209	90	29.87	2.480	2.892	2847.76	28.107	1334.01	1775.08	24.203	28.458	0.8505	0.2919	41.62
210	90	29.88	2.479	2.891	2846.73	28.108	1333.60	1775.24	24.195	28.444	0.8506	0.2919	41.63
211	80	29.85	2.442	2.890	2539.94	28.034	1186.73	1891.42	23.062	28.027	0.8228	0.2604	44.51
212	80	29.87	2.442	2.897	2539.86	28.148	1191.52	1888.95	22.937	28.033	0.8182	0.2602	44.50
213	80	29.87	2.441	2.895	2538.48	28.141	1190.59	1888.23	22.922	28.018	0.8181	0.2601	44.51
214	120	29.84	2.591	2.901	3801.62	27.463	1740.05	1394.77	25.983	29.646	0.8764	0.3893	31.32
215	120	29.84	2.594	2.904	3799.65	27.459	1738.89	1394.57	25.969	29.674	0.8752	0.3889	31.30
216	120	29.84	2.595	2.907	3799.52	27.458	1738.77	1395.53	25.987	29.691	0.8753	0.3887	31.30
217	110	29.89	2.550	2.888	3486.45	27.786	1614.60	1518.77	25.645	29.216	0.8778	0.3576	34.95
218	110	29.89	2.551	2.888	3487.61	27.757	1613.43	1517.69	25.662	29.227	0.8780	0.3577	34.94
219	110	29.89	2.551	2.889	3488.25	27.759	1613.86	1516.99	25.653	29.229	0.8777	0.3578	34.94
221	120	29.86	2.316	2.496	3800.46	27.163	1720.52	1231.20	23.182	26.559	0.8728	0.4156	23.94
222	120	29.85	2.317	2.497	3810.33	27.152	1724.29	1228.17	23.194	26.571	0.8729	0.416	23.94
223	110	29.86	2.289	2.489	3487.32	27.557	1601.67	1352.27	23.029	26.233	0.8779	0.3819	29.16
224	110	29.87	2.288	2.488	3482.58	27.556	1599.43	1352.64	23.005	26.221	0.8774	0.3815	29.16
225	110	29.88	2.289	2.488	3488.43	27.541	1601.23	1350.72	23.024	26.223	0.8780	0.3821	29.16
226	100	29.87	2.265	2.487	3165.73	27.891	1471.57	1488.92	22.743	25.932	0.8770	0.3468	33.48
227	100	29.88	2.266	2.488	3167.27	27.889	1472.18	1488.32	22.746	25.940	0.8769	0.3469	33.47
228	100	29.87	2.265	2.487	3163.55	27.896	1470.86	1489.58	22.733	25.931	0.8767	0.3466	33.46
229	90	29.88	2.240	2.488	2850.78	28.058	1333.10	1617.06	22.110	25.619	0.8631	0.312	37.53
230	90	29.90	2.241	2.490	2849.09	28.053	1332.10	1616.60	22.095	25.635	0.8619	0.3120	37.53
231	90	29.90	2.241	2.489	2850.39	28.056	1332.85	1616.64	22.103	25.630	0.8624	0.3121	37.53
232	80	29.89	2.219	2.492	2539.59	28.114	1189.96	1732.83	21.065	25.348	0.8310	0.2780	40.65
233	80	29.89	2.219	2.493	2538.20	28.124	1189.75	1733.05	21.048	25.355	0.8301	0.2777	40.65
234	80	29.89	2.219	2.493	2540.17	28.118	1190.41	1732.31	21.060	25.358	0.8305	0.2780	40.64
235	73	29.90	2.212	2.499	2310.64	28.143	1083.81	1818.14	20.088	25.266	0.7951	0.2526	41.73
236	73	29.89	2.211	2.497	2310.15	28.143	1083.58	1818.02	20.083	25.251	0.7953	0.2526	41.73
237	73	29.89	2.210	2.496	2309.44	28.145	1083.33	1816.90	20.063	25.242	0.7948	0.2526	41.73

Table II. Reduced Test Data and Calculated Performance Parameters - Configuration 2 (PPPP) (Continued).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
238	100	29.90	2.750	3.374	3172.23	28.033	1482.13	1772.66	26.995	31.250	0.8638	0.3071	42.64
239	100	29.89	2.753	3.379	3173.27	28.030	1482.47	1773.28	27.016	31.278	0.8637	0.3070	42.64
240	100	29.89	2.756	3.385	3173.30	28.031	1482.53	1773.84	27.024	31.306	0.8632	0.3069	42.64
241	100	29.93	2.055	2.195	3165.02	27.570	1454.34	1316.83	20.343	23.156	0.8785	0.3700	28.09
242	100	29.92	2.053	2.192	3162.91	27.568	1453.24	1316.72	20.330	23.124	0.8792	0.3701	28.10
243	100	29.93	2.052	2.192	3163.70	27.557	1453.04	1315.57	20.325	23.117	0.8792	0.3702	28.10
244	120	29.92	2.082	2.194	3812.82	26.621	1691.70	1059.87	20.428	23.538	0.8679	0.4460	16.22
245	120	29.92	2.083	2.195	3813.53	26.618	1691.82	1060.30	20.443	23.546	0.8682	0.4460	16.27
246	120	29.92	2.083	2.194	3812.34	26.617	1691.21	1060.38	20.439	23.542	0.8682	0.4459	16.20
247	110	29.92	2.074	2.198	3492.12	27.075	1575.84	1179.94	20.480	23.420	0.8745	0.4080	22.24
248	110	29.93	2.073	2.197	3489.28	27.078	1574.71	1179.82	20.460	23.408	0.8740	0.4078	22.26
249	110	29.92	2.072	2.196	3490.10	27.079	1575.12	1180.13	20.469	23.398	0.8748	0.4080	22.26
250	90	29.89	2.030	2.191	2848.76	27.911	1325.20	1449.35	19.907	22.805	0.8729	0.3335	33.88
251	90	29.90	2.031	2.191	2849.00	27.902	1324.88	1448.30	19.901	22.816	0.8722	0.3334	33.84
252	90	29.90	2.030	2.191	2846.92	27.904	1323.99	1449.23	19.898	22.805	0.8725	0.3333	33.87
253	80	29.95	2.009	2.188	2533.84	28.044	1184.30	1570.10	19.091	22.497	0.8486	0.2968	38.10
254	80	29.94	2.009	2.188	2536.87	28.051	1186.05	1569.34	19.099	22.496	0.8490	0.2971	38.10
255	80	29.94	2.008	2.188	2536.18	28.051	1185.72	1570.27	19.106	22.487	0.8496	0.2971	38.12
256	70	29.90	1.992	2.190	2220.73	28.124	1040.93	1685.16	17.907	22.245	0.8050	0.2600	41.17
257	70	29.89	1.991	2.189	2221.03	28.133	1041.41	1685.61	17.908	22.237	0.8053	0.2601	41.15
259	100	39.83	2.758	3.390	3164.86	28.066	1480.42	1784.55	27.081	31.323	0.8646	0.3059	42.63
260	100	39.83	2.756	3.387	3164.83	28.072	1480.70	1784.16	27.069	31.307	0.8646	0.3060	42.63
261	100	39.82	2.757	3.389	3164.88	28.076	1480.94	1785.13	27.080	31.318	0.8647	0.3059	42.63
262	110	39.82	2.806	3.381	3479.78	27.922	1619.36	1658.14	27.809	31.783	0.8750	0.3366	39.78
263	110	39.84	2.807	3.383	3481.41	27.917	1619.81	1657.48	27.816	31.793	0.8749	0.3367	39.78
264	110	39.83	2.805	3.379	3481.70	27.914	1619.83	1656.38	27.802	31.774	0.8750	0.3369	39.78
265	90	39.86	2.697	3.380	2847.53	28.132	1335.12	1902.15	25.910	30.723	0.8433	0.2755	45.25
266	90	39.87	2.695	3.376	2847.70	28.133	1335.26	1901.56	25.902	30.703	0.8436	0.2756	45.25
267	90	39.86	2.695	3.376	2847.84	28.133	1335.29	1901.96	25.910	30.704	0.8438	0.2756	45.25
268	90	34.89	2.693	3.371	2845.21	28.115	1333.23	1899.57	25.870	30.684	0.8431	0.2755	45.25
269	90	34.89	2.692	3.370	2846.49	28.117	1333.90	1898.96	25.871	30.682	0.8432	0.2757	45.25
270	90	34.90	2.693	3.371	2846.73	28.116	1333.99	1898.97	25.874	30.685	0.8432	0.2757	45.25
271	100	34.86	2.751	3.375	3168.04	28.051	1481.10	1779.06	27.039	31.254	0.8652	0.3066	42.64
272	100	34.86	2.752	3.377	3168.25	28.045	1480.89	1779.07	27.047	31.266	0.8651	0.3066	42.64
273	100	34.88	2.752	3.377	3167.48	28.039	1480.20	1779.12	27.047	31.267	0.8650	0.3065	42.64
274	110	34.84	2.803	3.373	3487.89	27.876	1620.46	1650.61	27.793	31.758	0.8752	0.3377	39.78
275	110	34.84	2.804	3.374	3485.42	27.878	1619.44	1651.40	27.785	31.761	0.8748	0.3374	39.78
276	110	34.84	2.806	3.378	3484.57	27.874	1618.84	1652.59	27.801	31.780	0.8748	0.3372	39.78
277	100	19.98	2.749	3.370	3170.23	27.982	1478.48	1762.96	26.879	31.240	0.8604	0.3070	42.66
278	100	19.98	2.750	3.371	3169.63	27.978	1477.98	1763.87	26.892	31.248	0.8606	0.3069	42.65
279	100	19.99	2.751	3.371	3170.42	27.971	1477.98	1761.99	26.877	31.253	0.8600	0.3070	42.65
280	110	19.98	2.807	3.375	3488.53	27.772	1614.72	1632.33	27.593	31.791	0.8680	0.3377	39.80
281	110	19.99	2.808	3.377	3490.14	27.764	1615.01	1631.51	27.600	31.802	0.8679	0.3378	39.80
282	110	19.98	2.808	3.377	3489.08	27.773	1615.05	1632.29	27.596	31.801	0.8678	0.3376	39.79
283	90	19.99	2.693	3.370	2856.14	28.066	1336.01	1883.52	25.794	30.691	0.8405	0.276	45.27
284	90	19.99	2.693	3.368	2853.28	28.065	1334.60	1884.36	25.782	30.683	0.8403	0.2764	45.27
285	90	19.98	2.690	3.365	2853.22	28.076	1335.11	1884.77	25.776	30.662	0.8407	0.2765	45.27
286	100	29.92	2.920	3.785	3171.68	28.026	1481.48	1840.02	28.023	32.829	0.8536	0.2957	43.99
287	100	29.92	2.919	3.784	3169.62	28.032	1480.87	1839.24	27.986	32.822	0.8527	0.2956	43.98
288	100	29.92	2.920	3.788	3167.17	28.029	1479.54	1840.15	27.982	32.835	0.8522	0.2953	43.98

Table II. Reduced Test Data and Calculated Performance Parameters - Configuration 2 (PPPP) (Continued).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
290	120	29.91	3.047	3.792	3798.79	27.588	1746.69	1587.10	29.409	33.938	0.8666	0.3540	39.27
291	120	29.92	3.050	3.797	3796.36	27.582	1745.19	1587.67	29.408	33.961	0.8659	0.3537	39.26
292	110	29.92	2.983	3.791	3479.20	27.868	1615.95	1718.08	28.866	33.388	0.8646	0.3242	41.80
293	110	29.92	2.982	3.790	3475.21	27.870	1614.21	1719.98	28.862	33.382	0.8646	0.3239	41.80
294	110	29.93	2.983	3.789	3477.85	27.851	1614.38	1718.48	28.878	33.385	0.8650	0.3242	41.80
295	90	29.93	2.844	3.779	2846.11	28.109	1333.37	1963.05	26.748	32.138	0.8323	0.2655	46.42
296	90	29.94	2.849	3.790	2846.04	28.085	1332.19	1964.00	26.783	32.187	0.8321	0.2653	46.43
297	90	29.93	2.852	3.798	2848.94	28.095	1334.02	1964.30	26.805	32.213	0.8321	0.2654	46.42
298	80	29.93	2.788	3.791	2536.12	28.119	1188.55	2076.29	25.201	31.610	0.7973	0.2364	48.15
299	80	29.93	2.788	3.792	2536.42	28.115	1188.53	2075.60	25.199	31.616	0.7970	0.2364	48.15
300	80	29.93	2.787	3.789	2536.39	28.113	1188.43	2075.74	25.202	31.606	0.7974	0.2364	48.15
301	120	29.88	3.258	4.305	3799.97	27.588	1747.25	1639.69	30.393	35.658	0.8523	0.3413	40.10
302	120	29.87	3.260	4.312	3799.60	27.596	1747.58	1639.73	30.382	35.674	0.8517	0.3411	40.09
303	120	29.88	3.262	4.315	3798.38	27.592	1746.74	1640.43	30.390	35.688	0.8515	0.3409	40.09
304	110	29.88	3.157	4.284	3481.11	27.866	1616.77	1767.35	29.711	34.856	0.8524	0.3131	42.8
305	110	29.89	3.160	4.289	3479.52	27.856	1615.42	1767.03	29.703	34.875	0.8517	0.3128	42.85
306	110	29.90	3.159	4.289	3477.38	27.860	1614.65	1767.60	29.690	34.871	0.8514	0.3126	42.85
307	100	29.89	3.094	4.276	3161.10	28.027	1476.62	1894.90	28.761	34.333	0.8377	0.2844	44.33
308	100	29.89	3.093	4.275	3161.13	28.027	1476.63	1893.69	28.743	34.329	0.8373	0.2844	44.3
309	100	29.89	3.093	4.272	3160.44	28.022	1476.03	1894.30	28.751	34.324	0.8376	0.2844	44.33
310	90	29.89	3.000	4.218	2842.63	28.083	1330.51	2009.31	27.370	33.536	0.8161	0.2567	46.26
311	90	29.89	3.001	4.220	2841.26	28.081	1329.77	2009.04	27.355	33.541	0.8156	0.2566	46.26
312	90	29.89	3.000	4.218	2844.82	28.083	1331.54	2008.33	27.378	33.534	0.8164	0.2569	46.26
313	80	29.89	2.904	4.146	2532.72	28.112	1186.67	2114.56	25.637	32.685	0.7844	0.2299	47.99
314	80	29.88	2.904	4.148	2532.83	28.113	1186.77	2114.30	25.634	32.688	0.7842	0.2299	48.00
315	80	29.88	2.902	4.143	2533.61	28.124	1187.61	2115.03	25.641	32.669	0.7849	0.2300	48.00
317	100	29.87	2.749	3.371	3168.20	28.026	1479.66	1776.27	27.022	31.240	0.8650	0.3068	42.64
318	100	29.88	2.751	3.374	3167.53	28.016	1479.03	1776.55	27.030	31.259	0.8647	0.3066	42.64
320	120	29.89	1.839	1.907	3792.56	25.667	1622.38	862.00	17.141	19.886	0.8620	0.4846	11.65
321	120	29.89	1.847	1.917	3799.85	25.705	1627.91	868.07	17.269	20.024	0.8624	0.4838	11.27
322	110	29.89	1.830	1.901	3484.45	26.107	1516.12	957.85	17.204	19.738	0.8716	0.4462	14.13
323	110	29.88	1.830	1.901	3484.40	26.112	1516.42	957.62	17.197	19.735	0.8714	0.4463	14.16
324	110	29.89	1.830	1.901	3481.53	26.114	1515.29	959.13	17.208	19.737	0.8719	0.4459	14.18
325	100	29.93	1.817	1.895	3164.90	26.659	1406.23	1075.52	17.183	19.524	0.8801	0.4062	20.11
326	100	29.93	1.817	1.895	3160.79	26.663	1404.63	1076.23	17.169	19.521	0.8795	0.4057	20.08
327	100	29.92	1.817	1.895	3162.96	26.666	1405.71	1076.04	17.176	19.524	0.8798	0.4060	20.07
328	90	29.90	1.815	1.907	2852.36	27.241	1295.02	1220.85	17.203	19.489	0.8827	0.3645	27.25
330	90	29.87	1.801	1.891	2839.54	27.234	1288.86	1211.04	16.993	19.259	0.8823	0.3650	27.27
331	80	29.90	1.772	1.872	2530.53	27.590	1163.62	1333.28	16.457	18.764	0.8770	0.3277	32.75
332	80	29.90	1.784	1.887	2536.73	27.686	1170.54	1341.22	16.537	18.981	0.8713	0.3266	32.68
333	80	29.91	1.789	1.893	2538.08	27.680	1170.90	1342.61	16.567	19.068	0.8689	0.3260	32.63
334	70	29.90	1.773	1.892	2222.24	27.969	1035.89	1475.94	15.781	18.788	0.8400	0.285	37.41
335	70	29.91	1.773	1.892	2215.31	27.972	1032.77	1477.79	15.750	18.793	0.8381	0.2847	37.41
336	70	29.90	1.772	1.892	2216.23	27.985	1033.69	1478.32	15.755	18.780	0.8389	0.2849	37.42
337	70	29.90	1.533	1.591	2217.11	26.627	983.91	1110.82	12.447	14.309	0.8699	0.3298	30.83
338	70	29.91	1.533	1.591	2216.28	26.629	983.60	1109.77	12.430	14.296	0.8695	0.3298	30.81
339	70	29.90	1.531	1.589	2214.63	26.636	983.15	1110.15	12.421	14.273	0.8703	0.3298	30.85
340	80	29.90	1.543	1.591	2537.17	25.914	1095.81	971.60	12.801	14.506	0.8825	0.3774	23.92
341	80	29.90	1.543	1.592	2528.49	25.930	1092.72	975.48	12.801	14.509	0.8823	0.3760	23.95
342	80	29.90	1.544	1.592	2530.04	25.924	1093.14	975.81	12.816	14.519	0.8827	0.3761	23.91

Table II. Reduced Test Data and Calculated Performance Parameters - Configuration 2 (PPPP) (Concluded).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
343	90	29.85	1.550	1.592	2843.29	25.153	1191.95	845.05	12.855	14.659	0.8769	0.4228	15.83
344	90	29.85	1.551	1.593	2843.77	25.159	1192.46	844.47	12.845	14.676	0.8753	0.4226	15.70
345	90	29.85	1.550	1.592	2844.36	25.158	1192.62	846.16	12.874	14.654	0.8786	0.4230	15.79
346	100	29.86	1.557	1.596	3168.35	24.473	1292.32	736.90	12.838	14.793	0.8679	0.4701	12.31
347	100	29.86	1.557	1.595	3166.48	24.473	1291.56	737.20	12.836	14.791	0.8678	0.4698	12.29
348	100	29.86	1.557	1.596	3165.16	24.478	1291.28	737.98	12.842	14.794	0.8681	0.4696	12.30
349	110	29.87	1.556	1.595	3483.62	23.852	1384.85	638.66	12.553	14.772	0.8498	0.5171	18.17
350	110	29.86	1.556	1.594	3486.01	23.856	1386.01	637.29	12.532	14.764	0.8489	0.5176	18.50
351	110	29.86	1.554	1.592	3480.36	23.870	1384.60	637.74	12.514	14.722	0.8500	0.5174	18.77

Table III. Reduced Test Data and Calculated Performance Parameters - Configuration 3 (PP).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
353	100	28.91	1.649	2.064	3161.32	28.084	1479.70	955.62	14.476	16.575	0.8734	0.2641	48.70
354	100	28.91	1.648	2.063	3161.81	28.083	1479.90	955.64	14.479	16.563	0.8742	0.2642	48.70
355	120	28.87	1.716	2.065	3797.39	27.845	1762.30	845.86	15.524	17.795	0.8724	0.3171	43.66
356	120	28.86	1.715	2.064	3797.18	27.864	1763.38	846.17	15.518	17.776	0.8730	0.3172	43.66
357	120	28.87	1.715	2.065	3799.76	27.844	1763.34	845.85	15.534	17.789	0.8732	0.3174	43.6
358	110	28.86	1.679	2.063	3487.39	27.999	1627.38	902.04	15.120	17.128	0.8828	0.2915	46.57
359	110	28.87	1.679	2.063	3485.91	27.992	1626.28	901.60	15.110	17.129	0.8821	0.2914	46.56
360	110	28.86	1.679	2.063	3482.44	28.003	1625.31	902.28	15.100	17.130	0.8815	0.2916	46.5
361	100	28.85	1.653	2.064	3162.05	28.068	1479.23	955.54	14.486	16.652	0.8699	0.2642	48.39
362	100	28.86	1.653	2.064	3161.92	28.063	1478.89	955.60	14.489	16.655	0.8700	0.2642	48.39
363	100	28.90	1.652	2.062	3164.31	28.078	1480.79	955.06	14.485	16.635	0.8707	0.2645	48.39
364	90	28.92	1.626	2.064	2852.11	28.100	1335.75	1000.56	13.666	16.134	0.8471	0.2383	50.13
365	90	28.91	1.625	2.063	2850.43	28.110	1335.40	1000.14	13.648	16.120	0.8466	0.2382	50.1
366	90	28.91	1.625	2.062	2850.05	28.108	1335.13	1001.48	13.666	16.116	0.8480	0.2383	50.13
367	80	28.91	1.595	2.063	2530.64	28.130	1186.43	1040.82	12.601	15.550	0.8103	0.2115	51.79
368	80	28.91	1.595	2.062	2531.47	28.132	1186.92	1042.35	12.622	15.540	0.8123	0.2116	51.79
369	80	28.91	1.595	2.061	2531.48	28.123	1186.55	1041.80	12.620	15.541	0.8120	0.2117	51.79
370	70	28.91	1.563	2.069	2217.12	28.124	1039.25	1082.71	11.486	14.921	0.7698	0.1850	53.55
371	70	28.92	1.563	2.067	2215.28	28.122	1038.29	1083.14	11.482	14.909	0.7701	0.1849	53.55
372	70	28.93	1.563	2.068	2215.90	28.111	1038.20	1082.78	11.486	14.916	0.7700	0.1849	53.55
373	100	28.92	1.655	2.070	3162.40	28.063	1479.11	957.84	14.526	16.681	0.8708	0.2637	48.51
374	100	28.92	1.655	2.071	3164.84	28.061	1480.13	958.17	14.543	16.696	0.8710	0.2638	48.51
375	100	28.92	1.654	2.070	3163.77	28.071	1480.15	957.35	14.520	16.678	0.8706	0.2639	48.51
376	120	29.90	2.394	4.018	3793.12	27.932	1765.85	1031.85	18.857	27.475	0.6863	0.2393	39.27
377	120	29.90	2.394	4.032	3794.41	27.939	1766.89	1031.98	18.861	27.483	0.6863	0.2392	39.28
378	120	29.90	2.392	4.040	3793.35	27.940	1766.45	1032.20	18.859	27.461	0.6868	0.2390	39.36
379	110	29.90	2.338	3.968	3476.89	28.039	1624.81	1083.92	18.088	26.821	0.6744	0.2202	40.50
380	110	29.91	2.339	4.007	3480.07	28.033	1625.93	1083.24	18.097	26.837	0.6743	0.2198	40.58
381	110	29.91	2.340	3.985	3479.81	28.028	1625.56	1083.15	18.097	26.844	0.6742	0.2201	40.51
382	100	29.91	2.254	4.000	3165.37	28.072	1481.00	1129.28	17.136	25.789	0.6645	0.2000	42.86
383	100	29.91	2.254	4.000	3166.36	28.074	1481.56	1129.13	17.138	25.798	0.6643	0.2000	42.84
384	100	29.90	2.253	3.984	3167.25	28.084	1482.51	1129.57	17.143	25.784	0.6649	0.2003	42.83
385	90	29.91	2.164	3.991	2848.53	28.097	1333.94	1169.57	15.957	24.633	0.6478	0.1801	45.04
386	90	29.90	2.161	3.991	2846.73	28.107	1333.53	1170.15	15.949	24.600	0.6483	0.1800	45.09
387	90	29.92	2.164	3.985	2845.88	28.091	1332.40	1169.66	15.947	24.645	0.6471	0.1800	45.03
388	80	29.91	2.088	4.001	2535.15	28.112	1187.81	1205.93	14.635	23.618	0.6197	0.1601	46.6
389	80	29.91	2.088	3.985	2535.51	28.116	1188.14	1206.59	14.643	23.615	0.6201	0.1604	46.67
390	80	29.91	2.089	4.000	2533.83	28.108	1187.01	1206.10	14.632	23.633	0.6191	0.1601	46.64
391	70	29.91	1.990	3.999	2217.46	28.118	1039.17	1242.70	13.189	22.227	0.5934	0.1401	48.71
392	70	29.92	1.992	3.974	2216.80	28.108	1038.49	1241.99	13.182	22.248	0.5925	0.1403	48.71
393	70	29.91	1.992	3.944	2217.41	28.115	1039.06	1242.49	13.187	22.251	0.5927	0.1407	48.72
394	100	29.91	2.509	5.388	3171.68	28.098	1485.27	1129.54	17.159	28.766	0.5965	0.1854	34.77
395	100	29.92	2.514	5.314	3175.32	28.082	1486.16	1128.51	17.172	28.828	0.5957	0.1862	34.80
396	100	29.91	2.509	5.412	3177.65	28.085	1487.41	1128.17	17.178	28.774	0.5970	0.1856	34.75
397	90	19.99	1.637	2.085	2848.59	28.044	1331.43	1003.92	13.723	16.347	0.8395	0.2365	50.11
398	90	19.99	1.636	2.084	2847.45	28.052	1331.28	1003.84	13.712	16.333	0.8396	0.2365	50.11
399	90	19.98	1.636	2.084	2848.46	28.054	1331.85	1003.87	13.717	16.332	0.8399	0.2366	50.11
400	100	19.98	1.657	2.076	3170.03	28.011	1479.92	953.51	14.522	16.718	0.8686	0.2638	48.73
401	100	19.98	1.660	2.084	3173.74	28.011	1481.65	953.53	14.539	16.776	0.8667	0.2636	48.72
402	100	19.99	1.655	2.074	3165.07	28.010	1477.58	950.72	14.457	16.685	0.8665	0.2636	48.72

Table III. Reduced Test Data and Calculated Performance Parameters - Configuration 3 (PP) (Concluded).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TO EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
403	110	19.99	1.691	2.083	3476.95	27.916	1617.69	901.97	15.118	17.354	0.8712	0.2888	46.54
404	110	19.98	1.692	2.084	3491.56	27.919	1624.71	900.06	15.148	17.360	0.8726	0.2900	46.54
405	110	19.98	1.692	2.085	3492.27	27.922	1625.17	900.53	15.157	17.367	0.8728	0.2900	46.54
406	100	28.92	1.652	2.070	3178.59	28.046	1485.76	956.98	14.596	16.642	0.8770	0.2651	48.73
407	100	28.92	1.654	2.073	3175.74	28.052	1484.74	957.32	14.585	16.664	0.8752	0.2646	48.72
408	100	28.92	1.653	2.073	3168.91	28.059	1481.96	957.89	14.558	16.657	0.8740	0.2641	48.72
409	100	34.94	1.647	2.060	3177.40	28.064	1486.16	956.03	14.567	16.539	0.8808	0.2658	48.73
410	100	34.95	1.647	2.060	3165.41	28.057	1480.18	957.72	14.541	16.549	0.8787	0.2647	48.73
411	100	34.94	1.647	2.060	3171.08	28.061	1483.03	956.57	14.548	16.540	0.8795	0.2653	48.73
412	110	34.93	1.679	2.061	3485.87	27.982	1625.68	907.40	15.212	17.127	0.8882	0.2915	46.55
413	110	34.95	1.680	2.063	3488.35	27.981	1626.79	906.65	15.211	17.147	0.8871	0.2915	46.55
414	110	34.93	1.679	2.062	3488.71	27.992	1627.61	907.04	15.213	17.133	0.8879	0.2916	46.55
415	90	34.87	1.628	2.067	2841.46	28.101	1330.78	1007.85	13.715	16.175	0.8479	0.2372	50.11
417	90	34.86	1.627	2.067	2843.43	28.112	1332.24	1007.53	13.714	16.165	0.8484	0.2374	50.11
418	90	39.90	1.625	2.063	2862.40	28.120	1341.50	1006.24	13.784	16.121	0.8550	0.2392	50.14
419	90	39.93	1.625	2.063	2850.21	28.112	1335.41	1007.69	13.749	16.123	0.8528	0.2382	50.16
420	90	39.92	1.625	2.064	2847.69	28.110	1334.12	1007.66	13.738	16.129	0.8517	0.2379	50.15
422	100	39.90	1.645	2.056	3162.99	28.087	1480.63	959.46	14.541	16.499	0.8813	0.2649	48.71
423	100	39.90	1.645	2.056	3159.07	28.087	1478.80	959.73	14.527	16.499	0.8805	0.2646	48.71
424	110	39.89	1.682	2.070	3481.98	28.023	1626.23	913.27	15.271	17.195	0.8881	0.2904	46.54
425	110	39.88	1.682	2.070	3480.01	28.033	1625.69	913.24	15.257	17.189	0.8876	0.2902	46.54
426	110	39.89	1.683	2.071	3478.88	28.019	1624.60	913.43	15.262	17.204	0.8871	0.2901	46.54
427	70	29.91	1.377	1.592	2218.85	27.904	1031.89	859.40	9.197	10.872	0.8459	0.2272	49.09
428	70	29.91	1.377	1.593	2216.47	27.894	1030.42	859.76	9.194	10.882	0.8449	0.2269	49.09
429	70	29.93	1.378	1.593	2216.50	27.884	1030.09	858.20	9.180	10.887	0.8432	0.2269	49.08
433	90	29.91	1.420	1.600	2840.04	27.468	1300.19	754.55	10.499	11.867	0.8847	0.2895	44.37
434	90	29.91	1.420	1.600	2849.85	27.461	1304.33	751.90	10.501	11.863	0.8852	0.2905	44.37
435	90	29.90	1.420	1.600	2852.39	27.476	1306.21	753.12	10.521	11.867	0.8866	0.2907	44.37
436	100	29.90	1.440	1.597	3167.63	27.125	1432.05	693.01	10.891	12.320	0.8840	0.3236	40.59
437	100	29.90	1.439	1.595	3161.18	27.134	1429.61	692.81	10.862	12.292	0.8836	0.3232	40.59
438	100	29.92	1.440	1.596	3160.63	27.113	1428.24	692.73	10.867	12.318	0.8822	0.3229	40.59
439	109	29.90	1.459	1.595	3466.03	26.788	1547.44	641.08	11.163	12.732	0.8768	0.3543	36.35
440	110	29.91	1.460	1.597	3473.87	26.789	1551.01	639.95	11.168	12.753	0.8757	0.3548	36.35
442	70	29.93	1.223	1.304	2205.19	24.530	901.56	509.43	6.163	6.946	0.8873	0.2948	43.12
443	70	29.92	1.222	1.303	2204.11	24.534	901.25	508.88	6.153	6.934	0.8873	0.2949	43.1
444	70	29.92	1.222	1.303	2203.07	24.541	901.08	508.79	6.147	6.925	0.8876	0.2949	43.15
445	79	29.91	1.240	1.309	2495.38	24.163	1004.94	472.00	6.560	7.430	0.8828	0.3315	37.66
446	78	29.94	1.241	1.309	2485.21	24.141	999.90	471.47	6.532	7.446	0.8772	0.3299	37.66
447	78	29.93	1.240	1.308	2482.19	24.157	999.39	471.84	6.524	7.424	0.8789	0.3298	37.6

Table IV. Reduced Test Data and Calculated Performance Parameters - Configuration 4 (PPTP).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
472	100	29.80	2.714	3.366	3158.75	27.944	1471.15	1777.81	27.044	30.899	0.8752	0.3060	44.67
473	100	29.80	2.713	3.363	3157.43	27.948	1470.75	1777.32	27.021	30.882	0.8750	0.3060	44.66
474	100	29.79	2.712	3.362	3156.73	27.955	1470.75	1778.74	27.031	30.874	0.8755	0.3060	44.67
475	80	29.80	2.722	3.778	2528.11	28.107	1184.30	2078.48	25.158	30.972	0.8123	0.2359	50.15
476	80	29.80	2.726	3.792	2528.40	28.114	1184.71	2078.65	25.158	31.010	0.8113	0.2356	50.14
477	80	29.80	2.725	3.790	2529.59	28.119	1185.50	2079.31	25.172	31.003	0.8119	0.2358	50.14
478	100	29.88	2.824	3.799	3168.05	27.953	1475.96	1842.10	28.095	31.953	0.8793	0.2951	48.0
479	100	29.88	2.822	3.791	3169.40	27.946	1476.23	1842.46	28.120	31.933	0.8806	0.2954	48.06
480	100	29.87	2.822	3.794	3169.14	27.956	1476.62	1842.15	28.103	31.934	0.8800	0.2953	48.07
481	120	29.87	2.973	3.789	3797.01	27.409	1734.54	1585.58	29.559	33.304	0.8876	0.3539	43.47
482	120	29.87	2.972	3.786	3797.25	27.414	1734.98	1585.76	29.559	33.291	0.8879	0.3541	43.46
483	120	29.87	2.973	3.790	3797.36	27.420	1735.38	1584.38	29.528	33.302	0.8867	0.3540	43.46
484	80	29.81	2.399	2.883	2533.18	28.079	1185.48	1896.03	23.019	27.541	0.8358	0.2600	47.13
485	80	29.81	2.397	2.880	2533.53	28.098	1186.43	1895.40	22.990	27.513	0.8359	0.2602	47.13
486	80	29.81	2.395	2.878	2533.22	28.106	1186.64	1893.69	22.969	27.495	0.8354	0.2602	47.13
487	100	29.83	2.491	2.890	3165.74	27.888	1471.45	1653.92	25.266	28.575	0.8842	0.3246	41.37
488	100	29.83	2.491	2.890	3165.01	27.899	1471.69	1653.24	25.239	28.573	0.8833	0.3245	41.37
489	100	29.83	2.493	2.893	3165.77	27.903	1472.23	1653.79	25.251	28.591	0.8832	0.3245	41.34
490	120	29.86	2.572	2.895	3803.24	27.248	1727.16	1385.49	26.025	29.442	0.8839	0.3898	34.40
491	120	29.86	2.572	2.895	3804.22	27.247	1727.57	1386.01	26.042	29.446	0.8844	0.3898	34.39
492	120	29.86	2.574	2.898	3803.55	27.248	1727.34	1386.69	26.049	29.470	0.8839	0.3896	34.39
502	80	29.85	1.993	2.191	2528.82	27.990	1179.70	1578.98	19.198	22.259	0.8625	0.2960	41.82
503	80	29.85	1.993	2.190	2528.38	27.991	1179.51	1578.87	19.193	22.256	0.8624	0.2960	41.82
504	80	29.85	1.993	2.191	2528.66	27.991	1179.65	1577.62	19.180	22.257	0.8617	0.2960	41.83
508	120	29.84	2.079	2.194	3798.07	26.414	1672.04	1054.02	20.396	23.494	0.8681	0.4442	20.03
509	120	29.85	2.080	2.195	3796.67	26.412	1671.30	1053.43	20.378	23.507	0.8669	0.4440	20.02
510	120	29.85	2.080	2.194	3801.39	26.414	1673.48	1052.12	20.377	23.500	0.8671	0.4446	20.04
511	100	29.82	2.706	3.361	3166.75	27.938	1474.52	1773.57	27.054	30.817	0.8779	0.3069	45.02
512	100	29.81	2.707	3.363	3166.89	27.935	1474.44	1774.74	27.076	30.829	0.8783	0.3069	45.02
513	100	29.81	2.706	3.360	3166.74	27.934	1474.34	1775.30	27.084	30.816	0.8789	0.3070	45.01
514	110	34.77	2.763	3.362	3477.00	27.744	1607.76	1650.43	27.835	31.377	0.8871	0.3370	42.37
515	110	34.77	2.766	3.366	3478.55	27.738	1608.14	1650.25	27.850	31.399	0.8870	0.3370	42.37
516	110	34.76	2.765	3.364	3482.51	27.740	1610.06	1649.43	27.867	31.393	0.8877	0.3374	42.37
517	100	34.80	2.711	3.370	3169.25	27.943	1476.00	1778.59	27.146	30.865	0.8795	0.3069	45.01
518	100	34.80	2.707	3.362	3169.50	27.943	1476.10	1778.78	27.152	30.825	0.8808	0.3072	45.01
519	100	34.79	2.707	3.360	3169.67	27.919	1474.92	1777.86	27.162	30.823	0.8812	0.3073	45.01
520	90	34.80	2.636	3.359	2845.53	28.059	1330.69	1902.89	25.970	30.108	0.8626	0.2759	47.86
521	90	34.81	2.635	3.357	2844.95	28.048	1329.93	1902.05	25.963	30.105	0.8624	0.2759	47.86
522	90	34.80	2.634	3.355	2845.35	28.056	1330.47	1902.03	25.959	30.092	0.8627	0.2760	47.86
523	90	39.75	2.637	3.362	2848.17	28.070	1332.46	1904.64	26.007	30.120	0.8635	0.2761	47.86
524	90	39.75	2.636	3.360	2848.33	28.076	1332.83	1904.42	26.000	30.108	0.8636	0.2761	47.86
525	90	39.74	2.636	3.360	2849.19	28.073	1333.07	1904.20	26.008	30.113	0.8637	0.2762	47.86
526	100	39.74	2.694	3.367	3160.63	27.984	1474.10	1785.11	27.133	30.696	0.8839	0.3062	45.71
527	100	39.74	2.700	3.379	3161.93	27.975	1474.24	1785.91	27.165	30.758	0.8832	0.3059	45.71
528	100	39.71	2.695	3.370	3161.59	27.989	1474.84	1786.22	27.152	30.709	0.8842	0.3062	45.71
529	110	39.75	2.769	3.373	3481.62	27.766	1611.15	1653.59	27.904	31.429	0.8878	0.3371	42.37
530	110	39.75	2.770	3.377	3480.95	27.778	1611.58	1654.80	27.906	31.443	0.8875	0.3369	42.37
531	110	39.75	2.766	3.369	3481.64	27.779	1611.91	1655.66	27.926	31.404	0.8893	0.3372	42.37
535	100	29.92	2.692	3.362	3165.18	27.959	1474.91	1774.96	27.041	30.682	0.8813	0.3068	45.71
536	100	29.92	2.693	3.363	3164.10	27.956	1474.27	1775.42	27.042	30.688	0.8812	0.306	45.71

Table IV. Reduced Test Data and Calculated Performance Parameters - Configuration 4 (PPTP) (Continued).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
537	100	29.92	2.693	3.364	3165.15	27.955	1474.69	1775.02	27.046	30.690	0.8813	0.3067	45.71
538	100	29.92	2.697	3.370	3178.17	27.948	1480.38	1770.76	27.099	30.726	0.8820	0.3078	45.71
539	100	29.93	2.697	3.370	3178.23	27.943	1480.18	1770.62	27.101	30.728	0.8820	0.3078	45.71
540	100	29.92	2.696	3.370	3177.75	27.955	1480.59	1771.92	27.105	30.720	0.8824	0.3078	45.71
541	110	29.92	2.763	3.363	3489.43	27.725	1612.39	1641.57	27.804	31.373	0.8862	0.3382	42.46
542	110	29.92	2.763	3.362	3488.83	27.724	1612.05	1640.97	27.790	31.372	0.8858	0.3381	42.45
543	110	29.92	2.763	3.363	3487.34	27.734	1611.96	1641.47	27.776	31.373	0.8854	0.3380	42.44
544	90	29.95	2.646	3.371	2855.70	28.050	1335.05	1898.46	26.010	30.213	0.8609	0.2765	47.68
545	90	29.95	2.645	3.370	2854.88	28.061	1335.17	1898.17	25.989	30.205	0.8604	0.2765	47.67
546	90	29.94	2.646	3.372	2853.76	28.054	1334.31	1898.00	25.982	30.217	0.8599	0.2763	47.66
547	80	29.94	2.571	3.361	2537.00	28.082	1187.42	2011.48	24.455	29.432	0.8309	0.2459	50.18
548	80	29.94	2.572	3.364	2536.80	28.079	1187.19	2010.93	24.449	29.446	0.8303	0.2458	50.18
549	80	29.94	2.572	3.364	2536.82	28.080	1187.24	2010.50	24.443	29.445	0.8301	0.2458	50.18
550	120	29.94	2.822	3.368	3802.53	27.384	1735.46	1513.43	28.281	31.934	0.8856	0.3683	39.59
551	120	29.93	2.827	3.375	3806.46	27.379	1736.95	1513.28	28.313	31.978	0.8854	0.3684	39.58
552	120	29.93	2.828	3.378	3805.16	27.384	1736.68	1513.83	28.308	31.989	0.8849	0.3682	39.57
553	100	29.90	2.700	3.373	3174.39	27.953	1478.91	1773.58	27.104	30.762	0.8811	0.3073	45.58
554	100	29.91	2.694	3.360	3172.68	27.959	1478.42	1772.90	27.074	30.698	0.8819	0.3076	45.59
555	100	29.90	2.707	3.380	3170.96	27.954	1477.35	1776.10	27.113	30.825	0.8796	0.3066	45.57
556	100	29.90	2.041	2.189	3172.28	27.397	1448.53	1307.07	20.367	22.956	0.8872	0.3715	31.98
557	100	29.91	2.041	2.189	3171.57	27.407	1448.71	1307.50	20.362	22.955	0.8870	0.3714	31.97
558	100	29.91	2.041	2.188	3172.63	27.405	1449.07	1306.84	20.360	22.949	0.8872	0.3716	31.97
559	100	29.88	2.255	2.491	3175.99	27.767	1469.77	1486.05	22.874	25.813	0.8861	0.3477	36.32
560	100	29.89	2.255	2.490	3165.95	27.770	1465.31	1490.48	22.867	25.807	0.8861	0.346	36.32
561	100	29.88	2.255	2.491	3171.54	27.762	1467.47	1486.85	22.858	25.810	0.8856	0.3472	36.31
562	120	29.90	2.307	2.492	3806.64	26.964	1710.70	1221.70	23.210	26.444	0.8777	0.4166	27.02
563	120	29.90	2.310	2.496	3805.98	26.967	1710.60	1223.91	23.246	26.484	0.8777	0.4162	27.0
564	120	29.90	2.309	2.495	3809.29	26.971	1712.31	1222.24	23.231	26.479	0.8774	0.4166	27.04
565	80	29.89	2.191	2.490	2539.51	28.082	1188.59	1741.24	21.190	24.992	0.8479	0.2780	44.04
566	80	29.89	2.191	2.490	2540.51	28.077	1188.85	1741.67	21.207	24.991	0.8486	0.2782	44.04
567	80	29.89	2.189	2.487	2539.58	28.062	1187.75	1740.44	21.197	24.970	0.8489	0.2782	44.03
568	80	29.90	1.784	1.896	2540.64	27.580	1167.85	1342.92	16.648	18.982	0.8770	0.3260	35.86
569	80	29.90	1.785	1.896	2538.05	27.579	1166.61	1344.12	16.646	18.986	0.8768	0.3257	35.85
570	80	29.89	1.784	1.896	2540.12	27.579	1167.58	1343.38	16.650	18.981	0.8772	0.3260	35.86
571	100	29.91	1.815	1.895	3172.20	26.472	1399.57	1065.96	17.190	19.486	0.8822	0.4072	23.26
572	100	29.91	1.814	1.895	3174.74	26.473	1400.75	1064.59	17.181	19.477	0.8821	0.4076	23.28
573	100	29.90	1.814	1.895	3174.57	26.461	1400.04	1064.48	17.186	19.481	0.8822	0.4075	23.27
574	120	29.89	1.827	1.893	3808.08	25.356	1609.29	834.78	16.872	19.695	0.8566	0.4891	12.60
575	120	29.91	1.828	1.894	3807.29	25.338	1607.79	833.58	16.856	19.711	0.8552	0.4889	12.59
576	120	29.91	1.828	1.894	3797.58	25.353	1604.68	836.86	16.869	19.707	0.8560	0.4876	12.60
577	100	29.92	1.562	1.600	3176.71	24.232	1282.95	727.55	12.836	14.888	0.8621	0.4700	13.04
578	100	29.92	1.561	1.599	3172.53	24.234	1281.40	727.25	12.812	14.878	0.8611	0.4695	12.82
579	100	29.93	1.561	1.600	3166.67	24.241	1279.39	729.31	12.821	14.882	0.8615	0.4686	12.93
580	100	49.46	2.672	3.319	3172.96	28.040	1482.84	1777.10	27.062	30.477	0.8879	0.3089	45.54
581	100	49.47	2.673	3.321	3174.86	28.042	1483.84	1777.30	27.079	30.486	0.8882	0.3090	45.54
582	100	49.54	2.675	3.325	3174.82	28.038	1483.58	1777.23	27.082	30.508	0.8877	0.3089	45.54
583	110	49.90	2.761	3.363	3489.69	27.864	1620.63	1659.38	27.967	31.349	0.8921	0.3382	42.36
584	110	49.89	2.761	3.365	3488.60	27.866	1620.20	1660.29	27.972	31.358	0.8920	0.3380	42.36
585	110	49.89	2.761	3.363	3489.10	27.866	1620.48	1659.64	27.964	31.350	0.8920	0.3381	42.36
586	110	20.00	2.774	3.376	3498.06	27.609	1609.66	1621.41	27.645	31.481	0.8781	0.3386	42.38

Table IV. Reduced Test Data and Calculated Performance Parameters - Configuration 4 (PPTP) (Concluded).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
587	110	20.01	2.777	3.379	3495.71	27.604	1608.27	1622.62	27.653	31.502	0.8778	0.3382	42.38
588	110	20.01	2.778	3.383	3498.26	27.613	1609.95	1622.79	27.667	31.521	0.8777	0.3383	42.38
589	100	20.01	2.703	3.371	3177.89	27.860	1475.59	1754.57	26.933	30.788	0.8748	0.3077	45.55
590	100	20.02	2.704	3.373	3182.02	27.855	1477.26	1752.48	26.941	30.796	0.8748	0.3081	45.5
591	100	20.02	2.704	3.372	3182.83	27.844	1477.02	1752.02	26.952	30.800	0.8751	0.3082	45.55
592	90	19.96	2.644	3.375	2859.14	28.006	1334.56	1884.27	25.887	30.196	0.8573	0.2768	47.86
593	90	19.96	2.645	3.374	2859.18	27.993	1333.95	1883.25	25.886	30.199	0.8572	0.2768	47.8
594	90	19.96	2.645	3.374	2861.68	27.994	1335.16	1883.33	25.909	30.203	0.8578	0.2770	47.86
595	100	29.95	2.926	4.075	3178.04	27.947	1480.27	1871.57	28.641	32.882	0.8710	0.2899	47.85
596	100	29.95	2.927	4.080	3179.01	27.950	1480.88	1871.72	28.649	32.896	0.8709	0.2899	47.85
597	100	29.96	2.926	4.070	3177.65	27.947	1480.09	1872.20	28.647	32.888	0.8710	0.2896	47.84
598	100	29.95	2.699	3.366	3176.70	27.934	1478.96	1772.21	27.122	30.745	0.8822	0.3078	45.54
599	100	29.96	2.698	3.365	3176.17	27.943	1479.18	1773.47	27.128	30.740	0.8825	0.3077	45.54
600	100	29.95	2.699	3.367	3176.97	27.947	1479.76	1772.84	27.121	30.745	0.8821	0.3078	45.54

Table V. Reduced Test Data and Calculated Performance Parameters - Configuration 5 (PPPPPT).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
601	100	29.92	3.459	3.808	3172.99	27.999	1480.66	2153.20	32.838	37.163	0.8836	0.3718	10.03
602	100	29.90	3.465	3.814	3173.70	27.987	1480.39	2156.10	32.903	37.207	0.8843	0.3717	9.61
603	100	29.90	3.464	3.812	3171.89	27.982	1479.29	2155.53	32.881	37.195	0.8840	0.3715	9.59
604	120	29.87	3.466	3.815	3795.36	27.477	1738.10	1775.39	33.001	37.212	0.8868	0.4444	14.66
605	120	29.87	3.473	3.823	3796.63	27.472	1738.33	1776.54	33.041	37.263	0.8867	0.4443	14.34
606	120	29.86	3.467	3.8 7	3794.71	27.478	1737.84	1776.74	33.020	37.219	0.8872	0.4443	14.88
607	110	29.87	3.471	3.819	3476.25	27.811	1611.30	1970.31	33.143	37.245	0.8899	0.4069	11.02
608	110	29.86	3.469	3.814	3475.57	27.807	1610.74	1970.38	33.143	37.230	0.8902	0.4070	10.45
609	110	29.87	3.468	3.813	3475.14	27.790	1609.57	1969.28	33.140	37.228	0.8902	0.4070	10.50
610	90	29.92	3.457	3.813	2844.44	28.074	1330.93	2350.49	32.048	37.150	0.8627	0.3331	10.51
611	90	29.92	3.460	3.815	2842.91	28.076	1330.28	2350.59	32.031	37.165	0.8618	0.3329	10.16
612	90	29.92	3.458	3.813	2843.02	28.072	1330.16	2350.81	32.039	37.157	0.8623	0.3330	10.20
613	100	29.92	3.462	3.812	3158.35	27.991	1473.44	2166.66	32.899	37.187	0.8847	0.3699	10.06
614	100	29.92	3.471	3.821	3160.19	27.993	1474.38	2166.45	32.914	37.246	0.8837	0.3699	9.33
615	100	29.91	3.466	3.818	3158.22	27.999	1473.77	2167.87	32.907	37.215	0.8842	0.3697	10.25
616	100	29.95	3.130	3.386	3159.78	27.947	1471.76	2021.78	30.762	34.634	0.8882	0.3846	11.39
617	100	29.95	3.127	3.382	3161.13	27.943	1472.19	2020.27	30.757	34.611	0.8886	0.3849	11.21
618	100	29.95	3.137	3.394	3158.67	27.945	1471.16	2024.47	30.794	34.687	0.8878	0.3841	11.38
619	120	29.95	3.116	3.384	3793.45	27.354	1729.43	1636.57	30.543	34.514	0.8849	0.4618	20.71
620	120	29.94	3.122	3.392	3793.69	27.361	1729.96	1639.59	30.594	34.569	0.8850	0.4614	20.59
621	120	29.95	3.118	3.390	3792.97	27.357	1729.38	1637.88	30.560	34.534	0.8849	0.4615	21.25
622	120	29.92	2.784	2.995	3793.80	27.173	1718.12	1475.20	27.717	31.572	0.8779	0.4829	27.21
623	120	29.92	2.786	2.998	3792.81	27.169	1717.46	1476.18	27.732	31.593	0.8778	0.4826	27.23
624	120	29.91	2.785	2.997	3792.63	27.184	1718.29	1477.07	27.733	31.587	0.8780	0.4826	27.22
625	100	29.92	2.807	2.998	3158.67	27.892	1468.37	1856.24	28.289	31.792	0.8898	0.4019	15.85
626	100	29.92	2.806	2.996	3159.76	27.889	1468.70	1855.12	28.285	31.780	0.8900	0.4021	15.86
627	100	29.92	2.803	2.992	3160.40	27.889	1469.01	1853.03	28.258	31.750	0.8900	0.4024	15.80
629	80	29.92	2.813	3.002	2539.28	28.066	1187.80	2209.87	26.906	31.852	0.8447	0.3229	10.21
630	80	29.91	2.811	2.999	2539.04	28.077	1188.13	2209.78	26.893	31.832	0.8448	0.3230	9.91
631	100	29.91	3.470	3.820	3159.36	27.973	1472.93	2169.46	32.974	37.240	0.8854	0.3698	9.88
632	100	29.91	3.475	3.828	3159.58	27.971	1472.97	2172.19	33.020	37.276	0.8858	0.3696	10.16
633	100	29.91	3.470	3.820	3158.00	27.971	1472.21	2170.38	32.976	37.240	0.8855	0.3696	9.77
634	120	29.93	2.409	2.591	3794.63	26.754	1692.05	1261.36	24.075	27.653	0.8706	0.5133	39.36
635	120	29.92	2.408	2.592	3795.89	26.766	1693.34	1260.35	24.054	27.646	0.8701	0.5135	39.52
636	120	29.92	2.409	2.593	3795.55	26.779	1693.98	1262.12	24.074	27.657	0.8704	0.5133	39.53
637	100	29.96	2.452	2.591	3167.19	27.700	1462.16	1625.81	25.017	28.139	0.8890	0.4285	23.13
638	100	29.96	2.452	2.591	3166.44	27.699	1461.80	1625.33	25.004	28.138	0.8886	0.4284	23.18
639	100	29.96	2.451	2.590	3167.59	27.701	1462.42	1625.08	25.007	28.132	0.8889	0.4286	23.09
640	80	29.95	2.464	2.591	2530.58	28.068	1183.82	1990.30	24.148	28.280	0.8539	0.3423	10.61
641	80	29.95	2.467	2.594	2532.22	28.076	1184.91	1991.17	24.168	28.305	0.8538	0.3424	10.49
642	80	29.95	2.466	2.593	2529.05	28.068	1183.09	1992.27	24.158	28.297	0.8537	0.3420	10.51
643	80	29.95	2.113	2.198	2531.18	27.949	1179.07	1711.99	20.865	23.961	0.8708	0.3723	17.56
644	80	29.96	2.115	2.200	2531.84	27.965	1180.05	1713.50	20.877	23.979	0.8706	0.3722	17.55
647	100	29.90	3.469	3.821	3162.43	28.004	1476.01	2162.00	32.856	37.237	0.8824	0.3701	9.60
648	100	29.88	3.462	3.812	3162.58	28.014	1476.60	2161.43	32.837	37.181	0.8832	0.3704	10.07
649	100	29.88	2.091	2.191	3160.09	27.086	1426.55	1322.75	20.768	23.656	0.8779	0.4657	32.19
650	100	29.88	2.089	2.189	3156.77	27.083	1424.93	1321.39	20.727	23.633	0.8770	0.4654	32.31
651	100	29.87	2.091	2.191	3157.27	27.100	1426.01	1322.88	20.741	23.654	0.8769	0.4652	32.28
652	120	29.92	2.062	2.195	3788.49	25.965	1639.50	990.52	19.449	23.252	0.8364	0.5577	45.27
653	120	29.91	2.063	2.195	3789.33	25.968	1640.05	990.68	19.454	23.261	0.8363	0.5577	45.24

Table V. Reduced Test Data and Calculated Performance Parameters - Configuration 5 (PPPPPT) (Continued).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TO EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
654	120	29.91	2.061	2.194	3788.48	25.966	1639.51	989.91	19.436	23.244	0.8362	0.5578	45.27
655	80	29.90	2.109	2.193	2527.22	27.963	1177.82	1708.68	20.781	23.907	0.8693	0.3722	16.62
656	80	29.91	2.113	2.197	2526.10	27.959	1177.10	1710.64	20.800	23.951	0.8684	0.3717	16.58
657	80	29.90	2.111	2.195	2526.28	27.963	1177.38	1709.06	20.778	23.929	0.8684	0.3719	16.57
658	100	19.92	3.471	3.823	3162.65	27.937	1472.57	2142.74	32.644	37.251	0.8763	0.3701	9.90
659	100	19.93	3.472	3.824	3163.06	27.950	1473.43	2143.16	32.640	37.256	0.8761	0.3701	9.90
660	100	19.93	3.482	3.837	3164.20	27.935	1473.21	2145.78	32.708	37.328	0.8762	0.3699	9.91
661	120	19.93	3.466	3.817	3792.55	27.398	1731.79	1758.53	32.759	37.212	0.8803	0.4440	15.38
662	120	19.93	3.475	3.828	3794.77	27.378	1731.54	1758.19	32.795	37.278	0.8798	0.4439	15.18
663	120	19.93	3.474	3.828	3795.12	27.382	1731.96	1759.00	32.809	37.269	0.8803	0.4439	15.55
664	90	19.93	3.469	3.828	2848.21	28.031	1330.65	2330.56	31.868	37.235	0.8559	0.3332	10.25
665	90	19.94	3.470	3.827	2847.45	28.022	1329.85	2328.66	31.844	37.238	0.8552	0.3331	9.98
666	90	19.93	3.464	3.821	2846.88	28.043	1330.59	2328.92	31.817	37.197	0.8554	0.3332	10.14
667	80	19.94	3.456	3.828	2531.37	28.052	1183.49	2509.22	30.471	37.137	0.8205	0.2961	13.68
668	80	19.94	3.451	3.822	2533.54	28.052	1184.52	2505.95	30.457	37.104	0.8209	0.2965	13.60
669	80	19.94	3.452	3.823	2534.70	28.055	1185.17	2506.48	30.475	37.114	0.8211	0.2966	13.62
670	80	19.70	3.594	4.029	2528.71	28.134	1185.73	2580.16	31.208	38.112	0.8188	0.2913	15.35
671	80	19.89	3.602	4.034	2528.94	27.959	1178.44	2553.86	31.087	38.167	0.8145	0.2912	15.23
672	80	19.99	3.589	4.020	2533.58	28.077	1185.60	2566.59	31.167	38.078	0.8185	0.2921	15.31
672	80	19.66	3.551	3.963	2529.19	28.021	1181.16	2543.54	30.896	37.812	0.8171	0.2928	15.0
674	80	19.94	3.122	3.384	2532.94	28.054	1184.34	2360.93	28.686	34.563	0.8299	0.3084	10.98
676	100	29.89	3.471	3.822	3160.84	28.003	1475.22	2166.07	32.902	37.249	0.8833	0.3699	9.32
677	100	29.89	3.473	3.825	3160.73	28.011	1475.57	2167.62	32.916	37.263	0.8833	0.3698	9.3
676	100	29.89	3.473	3.824	3159.82	28.005	1474.86	2167.31	32.908	37.260	0.8832	0.3698	9.10
679	110	34.82	3.463	3.809	3487.44	27.861	1619.40	1972.38	33.224	37.190	0.8934	0.4086	10.97
680	110	34.81	3.468	3.816	3485.94	27.860	1618.64	1975.37	33.262	37.224	0.8936	0.4082	11.00
681	110	34.81	3.468	3.816	3484.38	27.859	1617.63	1976.06	33.260	37.224	0.8935	0.4080	11.00
683	100	34.82	3.465	3.815	3161.04	28.048	1477.70	2171.61	32.936	37.206	0.8852	0.3701	9.43
684	100	34.81	3.465	3.815	3158.94	28.051	1476.85	2173.28	32.936	37.203	0.8853	0.3699	9.46
685	90	34.82	3.459	3.816	2846.75	28.121	1334.21	2356.85	32.108	37.165	0.8639	0.3333	10.28
686	90	34.82	3.461	3.817	2844.82	28.112	1332.88	2357.63	32.107	37.173	0.8637	0.3331	10.30
687	90	34.82	3.458	3.815	2847.26	28.117	1334.27	2356.34	32.111	37.158	0.8642	0.3334	10.32
688	95	39.93	3.468	3.822	3022.54	28.081	1414.61	2260.44	32.742	37.229	0.8795	0.3537	9.37
689	95	39.93	3.464	3.816	3021.37	28.080	1413.99	2259.66	32.720	37.201	0.8795	0.3538	9.40
690	95	39.92	3.463	3.815	3019.70	28.086	1413.52	2260.74	32.710	37.192	0.8795	0.3536	9.40
691	100	39.90	3.463	3.811	3162.75	28.038	1477.94	2174.33	33.007	37.187	0.8876	0.3705	9.24
692	100	39.90	3.461	3.809	3161.17	28.037	1477.14	2175.06	33.003	37.177	0.8877	0.3703	9.22
693	100	39.89	3.459	3.806	3160.35	28.039	1476.91	2174.86	32.988	37.159	0.8877	0.3704	9.19
694	110	39.89	3.471	3.819	3478.62	27.861	1615.32	1986.90	33.384	37.249	0.8962	0.4072	10.74
695	110	39.88	3.471	3.820	3478.19	27.868	1615.49	1987.16	33.377	37.251	0.8960	0.4071	10.75
696	110	39.89	3.471	3.819	3477.07	27.857	1614.32	1986.58	33.370	37.251	0.8958	0.4070	10.71
697	110	44.81	3.466	3.814	3474.40	27.893	1615.19	1990.26	33.362	37.215	0.8965	0.4069	10.81
698	110	44.80	3.467	3.814	3475.08	27.896	1615.70	1989.96	33.360	37.216	0.8964	0.4069	10.82
699	110	44.80	3.464	3.811	3475.24	27.900	1615.99	1989.42	33.348	37.200	0.8964	0.4071	10.80
704	100	29.96	3.474	3.825	3159.13	27.984	1473.42	2169.82	32.964	37.272	0.8844	0.3696	9.37
705	100	29.96	3.475	3.828	3161.20	27.985	1474.45	2170.82	32.999	37.278	0.8852	0.3698	9.03
706	100	29.98	3.911	4.430	3167.62	27.992	1477.79	2319.31	35.320	40.175	0.8792	0.3553	9.49
707	100	29.97	3.915	4.4 0	3168.22	27.999	1478.44	2319.92	35.327	40.198	0.8788	0.3553	9.65
708	100	29.97	3.922	4.445	3168.70	27.996	1478.51	2322.16	35.370	40.241	0.8790	0.3551	9.50
709	100	29.96	3.683	4.106	3163.50	27.993	1475.95	2244.39	34.133	38.711	0.8817	0.3625	8.94

Table V. Reduced Test Data and Calculated Performance Parameters - Configuration 5 (PPPPPT) (Concluded).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
710	100	29.95	3.674	4.094	3163.96	28.005	1476.78	2244.60	34.127	38.653	0.8829	0.3628	9.15
711	100	29.95	3.674	4.095	3163.78	28.011	1477.02	2244.79	34.120	38.654	0.8827	0.3628	9.18
712	120	29.95	3.679	4.091	3798.93	27.510	1741.79	1851.47	34.407	38.686	0.8894	0.4357	12.09
713	120	29.94	3.676	4.089	3797.75	27.507	1741.11	1851.80	34.406	38.665	0.8898	0.435	12.74
714	120	29.94	3.686	4.100	3800.56	27.490	1741.28	1852.08	34.458	38.732	0.8897	0.4356	12.89
715	100	29.97	3.666	4.084	3168.66	27.992	1478.30	2235.27	34.051	38.602	0.8821	0.3636	9.20
716	100	29.98	3.667	4.085	3169.89	27.992	1478.87	2234.50	34.052	38.609	0.8820	0.3637	9.15
717	100	29.96	3.662	4.079	3168.77	28.000	1478.77	2235.67	34.048	38.573	0.8827	0.3637	9.63
718	100	29.96	1.906	1.993	3169.20	26.369	1392.82	1129.66	18.271	20.949	0.8722	0.4947	39.42
719	100	29.95	1.905	1.993	3168.92	26.373	1392.91	1130.30	18.277	20.941	0.8728	0.4947	39.44
720	100	29.95	1.906	1.993	3170.05	26.382	1393.88	1129.70	18.268	20.944	0.8722	0.4949	39.42
721	100	29.91	1.666	1.738	3173.89	24.799	1311.84	829.01	14.278	16.893	0.8452	0.5482	48.36
722	100	29.90	1.666	1.738	3169.13	24.809	1310.37	829.90	14.267	16.886	0.8449	0.5474	48.37
723	100	29.88	1.664	1.736	3169.57	24.830	1311.67	831.08	14.277	16.847	0.8474	0.5481	48.36

Table VI. Reduced Test Data and Calculated Performance Parameters - Configuration 6 (PPTPTT).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
724	100	29.89	3.477	3.825	3172.03	27.932	1476.68	2155.94	32.948	37.294	0.8835	0.3711	8.15
725	100	29.89	3.476	3.824	3171.33	27.932	1476.38	2156.02	32.942	37.286	0.8835	0.3711	8.10
726	100	29.89	3.477	3.825	3168.53	27.927	1474.79	2157.37	32.940	37.293	0.8833	0.3707	8.28
727	120	29.91	3.480	3.8 3	3798.88	27.295	1728.18	1767.95	33.113	37.310	0.8875	0.4442	15.92
728	120	29.89	3.472	3.825	3800.26	27.303	1729.31	1765.09	33.062	37.259	0.8874	0.4446	16.30
729	120	29.90	3.475	3.827	3800.45	27.301	1729.30	1765.40	33.071	37.277	0.8872	0.4446	15.90
730	110	29.89	3.478	3.822	3482.34	27.657	1605.21	1958.36	33.183	37.300	0.8896	0.4075	10.35
731	110	29.89	3.476	3.819	3484.60	27.657	1606.22	1957.17	33.185	37.285	0.8900	0.4079	10.35
732	110	29.89	3.483	3.822	3485.04	27.657	1606.43	1957.96	33.202	37.331	0.8894	0.4079	7.87
733	90	29.88	3.463	3.815	2850.09	28.048	1332.31	2348.25	32.112	37.194	0.8634	0.3337	8.79
734	90	29.88	3.465	3.817	2850.45	28.040	1332.12	2348.09	32.122	37.206	0.8634	0.3337	8.54
735	90	29.88	3.463	3.814	2847.87	28.042	1331.01	2347.81	32.087	37.189	0.8628	0.3335	8.66
736	100	29.88	3.474	3.820	3163.62	27.929	1472.63	2160.38	32.932	37.270	0.8836	0.3703	7.96
737	100	29.88	3.472	3.818	3162.99	27.932	1472.49	2160.21	32.919	37.257	0.8836	0.3703	8.12
738	100	29.89	3.474	3.821	3162.20	27.929	1471.95	2161.27	32.931	37.273	0.8835	0.3701	7.97
739	100	29.89	3.475	3.821	3167.92	27.909	1473.54	2157.31	32.954	37.280	0.8840	0.3708	7.90
740	100	29.88	3.468	3.813	3164.18	27.922	1472.49	2157.42	32.901	37.229	0.8838	0.3706	8.12
741	100	29.88	3.469	3.814	3163.95	27.934	1473.01	2159.21	32.912	37.234	0.8839	0.3705	8.05
742	100	29.90	3.134	3.390	3165.48	27.895	1471.71	2011.92	30.724	34.661	0.8864	0.3851	11.34
743	100	29.91	3.130	3.384	3164.07	27.901	1471.34	2010.64	30.685	34.630	0.8861	0.3852	11.05
744	100	29.91	3.132	3.386	3164.23	27.890	1470.84	2010.13	30.690	34.644	0.8859	0.3851	10.79
745	120	29.91	3.119	3.394	3796.47	27.206	1721.44	1625.63	30.528	34.539	0.8839	0.4617	22.73
746	120	29.90	3.115	3.389	3796.85	27.201	1721.32	1624.01	30.506	34.506	0.8841	0.4620	22.71
747	120	29.90	3.115	3.389	3796.48	27.206	1721.44	1624.37	30.504	34.509	0.8840	0.4619	22.73
748	120	29.92	2.773	2.985	3794.21	26.995	1707.06	1454.21	27.506	31.466	0.8742	0.4636	28.65
749	120	29.91	2.771	2.984	3795.39	26.999	1707.85	1452.96	27.487	31.452	0.8739	0.4638	28.83
750	120	29.91	2.777	2.992	3796.21	27.013	1709.13	1456.76	27.550	31.508	0.8744	0.4634	28.00
751	100	29.91	2.800	2.989	3160.70	27.821	1465.54	1840.99	28.147	31.724	0.8872	0.4026	16.22
752	100	29.91	2.800	2.989	3160.91	27.822	1465.73	1840.87	28.145	31.726	0.8871	0.4027	15.79
753	100	29.91	2.800	2.988	3160.45	27.812	1464.96	1840.95	28.153	31.726	0.8874	0.4026	15.81
754	80	29.88	2.809	2.994	2546.46	28.081	1191.77	2208.41	26.951	31.808	0.8473	0.3242	8.54
755	80	29.89	2.809	2.994	2545.73	28.077	1191.28	2207.79	26.939	31.809	0.8469	0.3241	8.40
756	80	29.89	2.810	2.995	2546.82	28.075	1191.68	2207.79	26.953	31.821	0.8470	0.3241	8.37
757	100	29.91	3.479	3.828	3156.13	27.928	1469.07	2167.27	32.960	37.307	0.8835	0.3692	8.34
758	100	29.90	3.482	3.831	3168.21	27.926	1474.59	2160.70	32.988	37.328	0.8837	0.3705	8.06
759	100	29.91	3.480	3.828	3168.04	27.927	1474.54	2159.27	32.964	37.310	0.8835	0.3706	8.08
760	120	29.91	2.424	2.595	3794.49	26.586	1681.34	1244.38	23.901	27.823	0.8590	0.5130	37.2
761	120	29.90	2.423	2.593	3793.25	26.602	1681.81	1245.03	23.891	27.815	0.8589	0.5130	36.95
762	120	29.90	2.423	2.594	3793.23	26.596	1681.41	1245.51	23.906	27.813	0.8595	0.5129	37.2
763	100	29.90	2.457	2.599	3163.50	27.587	1454.51	1619.65	24.995	28.194	0.8865	0.4274	24.50
764	100	29.89	2.454	2.596	3162.77	27.594	1454.58	1619.37	24.978	28.167	0.8868	0.4275	24.56
765	100	29.89	2.455	2.597	3161.12	27.588	1453.49	1619.93	24.979	28.173	0.8866	0.4272	24.53
766	80	29.90	2.470	2.597	2530.77	28.056	1183.40	1996.47	24.235	28.340	0.8552	0.3420	10.54
767	80	29.89	2.467	2.594	2528.80	28.061	1182.70	1996.46	24.212	28.313	0.8552	0.3419	10.60
768	80	29.89	2.467	2.594	2530.44	28.065	1183.61	1996.36	24.223	28.310	0.8556	0.3421	10.67
769	80	29.89	2.109	2.193	2529.34	27.868	1174.80	1700.57	20.771	23.899	0.8691	0.3725	17.58
770	80	29.88	2.108	2.192	2530.12	27.870	1175.22	1700.70	20.778	23.892	0.8696	0.3727	17.51
771	80	29.89	2.109	2.192	2529.84	27.868	1175.03	1700.85	20.778	23.897	0.8695	0.3726	17.54
772	100	29.90	2.093	2.194	3162.72	26.878	1416.78	1308.45	20.720	23.684	0.8748	0.4657	33.13
773	100	29.89	2.092	2.192	3162.97	26.897	1417.91	1308.45	20.706	23.664	0.8750	0.4659	33.05

Table VI. Reduced Test Data and Calculated Performance Parameters - Configuration 6 (PPTPTT) (Continued).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
775	120	29.90	2.061	2.194	3794.86	25.728	1627.21	970.40	19.262	23.233	0.8291	0.5587	45.85
776	120	29.89	2.060	2.193	3795.04	25.728	1627.28	970.06	19.256	23.226	0.8291	0.5589	45.84
777	120	29.89	2.060	2.193	3795.11	25.711	1626.26	968.90	19.246	23.225	0.8287	0.5589	45.84
778	80	19.94	3.617	4.055	2535.10	28.047	1185.02	2575.01	31.322	38.268	0.8185	0.2915	14.77
779	80	19.93	3.623	4.064	2534.87	28.057	1185.37	2579.05	31.357	38.308	0.8185	0.2913	14.79
780	80	19.94	3.634	4.078	2535.27	28.040	1184.81	2580.47	31.398	38.384	0.8180	0.2911	14.60
781	100	29.89	3.884	4.385	3163.32	27.959	1474.07	2300.71	35.030	40.008	0.8756	0.3558	8.11
782	100	29.87	3.883	4.385	3162.61	27.971	1474.34	2301.97	35.027	40.001	0.8757	0.3558	8.27
783	100	29.88	3.886	4.388	3164.74	27.956	1474.56	2299.68	35.034	40.021	0.8754	0.3559	7.96
784	100	29.87	3.672	4.087	3161.21	27.962	1473.24	2234.37	33.993	38.638	0.8798	0.3627	7.89
785	100	29.87	3.674	4.090	3160.36	27.958	1472.60	2235.85	34.013	38.656	0.8799	0.3625	7.60
786	100	29.87	3.668	4.082	3161.68	27.961	1473.39	2232.67	33.974	38.615	0.8798	0.3628	7.76
787	120	29.88	3.673	4.087	3796.69	27.358	1731.16	1838.98	34.345	38.650	0.8886	0.4356	14.09
788	120	29.88	3.677	4.091	3795.97	27.353	1730.49	1839.26	34.350	38.673	0.8882	0.4354	14.05
789	120	29.87	3.671	4.080	3796.24	27.357	1730.87	1837.20	34.309	38.632	0.8881	0.4357	13.51
790	100	29.88	3.473	3.820	3162.10	27.948	1472.91	2158.85	32.871	37.263	0.8821	0.3701	8.16
791	100	29.87	3.471	3.818	3162.03	27.941	1472.48	2160.75	32.907	37.249	0.8834	0.3702	8.40
792	100	29.88	3.470	3.817	3162.40	27.940	1472.60	2158.39	32.877	37.243	0.8828	0.3703	8.44
793	100	19.92	3.467	3.812	3164.88	27.885	1470.87	2137.29	32.645	37.219	0.8771	0.3707	8.4
794	100	19.92	3.476	3.824	3166.63	27.863	1470.54	2137.24	32.687	37.282	0.8768	0.3706	8.7
795	100	19.92	3.476	3.824	3166.09	27.856	1469.91	2137.39	32.692	37.284	0.8769	0.3705	8.84
796	120	19.94	3.463	3.813	3799.92	27.192	1722.11	1743.22	32.783	37.191	0.8815	0.4450	16.89
797	120	19.94	3.477	3.8 2	3799.70	27.200	1722.55	1749.34	32.886	37.292	0.8819	0.4443	16.89
798	120	19.94	3.476	3.830	3800.26	27.196	1722.53	1748.42	32.879	37.282	0.8819	0.4445	16.89
799	90	19.93	3.444	3.815	2849.37	27.992	1329.34	2332.01	31.945	37.051	0.8622	0.3337	16.54
800	90	19.95	3.447	3.820	2849.69	27.980	1328.93	2332.02	31.962	37.073	0.8621	0.3336	16.83
801	90	19.95	3.446	3.818	2850.32	27.983	1329.33	2330.67	31.948	37.066	0.8619	0.3337	16.69
802	80	19.94	3.463	3.829	2535.69	28.041	1185.06	2520.66	30.674	37.191	0.8248	0.2966	11.57
803	80	19.95	3.469	3.836	2534.23	28.041	1184.37	2522.34	30.677	37.236	0.8239	0.296	10.94
804	80	19.94	3.457	3.827	2534.39	28.041	1184.44	2521.09	30.664	37.145	0.8255	0.2965	13.31
805	80	19.94	3.132	3.392	2534.05	28.035	1184.04	2369.98	28.828	34.651	0.8320	0.3082	8.89
806	80	19.94	3.128	3.386	2532.90	28.042	1183.77	2369.53	28.803	34.618	0.8320	0.3082	9.32
807	80	19.94	3.143	3.407	2534.71	28.036	1184.39	2376.19	28.910	34.738	0.8322	0.3079	9.30
808	110	34.86	3.481	3.827	3482.46	27.701	1607.80	1967.92	33.293	37.316	0.8922	0.4074	10.62
809	110	34.88	3.479	3.825	3481.36	27.714	1608.02	1969.60	33.296	37.308	0.8925	0.4073	10.53
810	110	34.88	3.479	3.826	3479.94	27.710	1607.14	1969.96	33.293	37.309	0.8924	0.4071	10.57
811	100	34.88	3.473	3.819	3165.00	27.965	1475.15	2166.94	33.004	37.259	0.8858	0.3705	8.00
812	100	34.88	3.474	3.822	3162.09	27.972	1474.17	2168.89	32.995	37.272	0.8852	0.3701	7.98
813	100	34.88	3.472	3.819	3162.66	27.972	1474.45	2168.49	32.994	37.258	0.8856	0.3702	7.98
814	90	34.88	3.465	3.818	2850.86	28.085	1334.45	2358.48	32.217	37.206	0.8659	0.3338	8.45
815	90	34.88	3.465	3.817	2851.77	28.090	1335.12	2358.66	32.224	37.205	0.8661	0.3339	8.41
816	90	34.88	3.467	3.821	2852.20	28.089	1335.23	2359.29	32.240	37.223	0.8661	0.3338	8.3
817	95	39.76	3.475	3.826	3009.00	28.068	1407.63	2270.68	32.758	37.274	0.8789	0.3520	7.79
818	95	39.75	3.462	3.810	3004.37	28.073	1405.72	2268.19	32.666	37.183	0.8785	0.3520	7.86
819	95	39.85	3.464	3.812	3009.03	28.075	1407.99	2267.80	32.709	37.197	0.8793	0.3524	7.97
820	100	39.84	3.477	3.825	3156.68	27.940	1469.98	2173.60	33.047	37.294	0.8861	0.3693	8.00
821	100	39.87	3.474	3.821	3158.08	27.978	1472.60	2176.16	33.057	37.269	0.8870	0.3696	8.06
822	100	39.87	3.477	3.825	3157.09	27.982	1472.35	2177.43	33.061	37.288	0.8866	0.3694	8.0
823	110	39.87	3.478	3.826	3474.03	27.764	1607.57	1982.97	33.390	37.301	0.8952	0.4065	10.66
824	110	39.85	3.475	3.823	3473.40	27.757	1606.84	1980.78	33.357	37.277	0.8948	0.4065	11.29

Table VI. Reduced Test Data and Calculated Performance Parameters - Configuration 6 (PPTPTT) (Concluded).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
825	110	39.85	3.473	3.827	3473.33	27.754	1606.62	1982.39	33.387	37.263	0.8960	0.4063	13.51
826	100	29.95	3.474	3.822	3162.24	27.935	1472.30	2162.24	32.939	37.268	0.8838	0.3701	8.57
827	100	29.95	3.473	3.820	3162.71	27.927	1472.08	2161.39	32.940	37.262	0.8840	0.3702	8.56
828	100	29.95	3.474	3.822	3163.11	27.926	1472.20	2161.54	32.948	37.271	0.8840	0.3702	8.60
829	100	29.94	1.916	2.006	3170.25	26.227	1385.77	1125.47	18.308	21.101	0.8676	0.4929	40.17
830	100	29.93	1.917	2.007	3167.99	26.230	1384.96	1127.09	18.319	21.116	0.8676	0.492	40.18
831	100	29.93	1.916	2.007	3169.32	26.230	1385.51	1125.91	18.308	21.112	0.8672	0.4926	40.18
832	100	29.92	1.673	1.748	3160.49	24.703	1301.24	829.61	14.283	17.024	0.8390	0.5433	49.13
833	100	29.92	1.673	1.748	3157.23	24.706	1300.04	830.35	14.280	17.023	0.8389	0.5427	49.14
834	100	29.92	1.673	1.748	3157.54	24.714	1300.60	830.58	14.281	17.019	0.8391	0.5428	49.14

Table VII. Reduced Test Data and Calculated Performance Parameters - Configuration 7 (PPPPLP).

RDG	PCT NDES	PTO	PTO/PT3	PTO/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/CO	FLOWANG
835	100	29.91	3.443	3.797	3166.18	28.006	1477.85	2155.86	32.787	37.044	0.8851	0.3713	13.46
836	100	29.90	3.442	3.798	3165.54	28.018	1478.18	2156.65	32.791	37.038	0.8853	0.3712	13.94
837	100	29.92	3.445	3.800	3166.48	28.005	1477.94	2155.25	32.794	37.061	0.8849	0.3712	13.40
838	120	29.89	3.461	3.815	3792.83	27.479	1737.05	1777.95	33.025	37.177	0.8883	0.4441	16.13
839	120	29.90	3.466	3.819	3793.61	27.477	1737.30	1778.62	33.046	37.212	0.8881	0.4441	15.68
840	120	29.89	3.464	3.817	3792.51	27.478	1736.83	1778.57	33.035	37.201	0.8880	0.4440	15.64
841	110	29.89	3.456	3.809	3481.00	27.802	1612.99	1967.12	33.145	37.142	0.8924	0.4078	13.86
842	110	29.90	3.458	3.814	3481.69	27.802	1613.28	1967.31	33.155	37.158	0.8923	0.4077	14.43
843	110	29.89	3.458	3.809	3481.57	27.800	1613.12	1967.12	33.153	37.152	0.8923	0.4079	13.57
844	90	29.92	3.441	3.810	2843.51	28.092	1331.35	2346.26	31.960	37.033	0.8630	0.3331	15.63
845	90	29.92	3.439	3.808	2842.85	28.093	1331.06	2346.82	31.959	37.018	0.8633	0.3331	15.64
846	90	29.92	3.438	3.806	2843.21	28.096	1331.37	2346.13	31.951	37.011	0.8633	0.3332	15.55
847	100	29.91	3.459	3.820	3160.64	27.996	1474.75	2167.03	32.923	37.165	0.8859	0.3700	13.71
848	100	29.92	3.467	3.829	3160.43	27.989	1474.29	2168.96	32.959	37.218	0.8856	0.3697	13.52
849	100	29.92	3.471	3.833	3159.96	27.993	1474.27	2170.54	32.973	37.248	0.8852	0.3695	13.24
850	100	29.93	3.121	3.380	3161.14	27.962	1473.19	2018.47	30.709	34.557	0.8886	0.3850	13.65
851	100	29.93	3.121	3.380	3160.81	27.953	1472.59	2017.60	30.701	34.559	0.8884	0.3849	13.63
852	100	29.92	3.117	3.376	3160.88	27.953	1472.61	2016.69	30.688	34.529	0.8888	0.3851	13.70
853	120	29.92	3.120	3.386	3796.74	27.334	1729.65	1634.79	30.559	34.550	0.8845	0.4621	19.98
854	120	29.92	3.120	3.387	3795.93	27.345	1729.98	1635.43	30.552	34.547	0.8844	0.4620	20.06
855	120	29.92	3.119	3.385	3796.14	27.342	1729.93	1634.81	30.544	34.539	0.8844	0.4621	20.03
856	120	29.92	2.798	3.006	3795.31	27.137	1716.56	1478.75	27.832	31.704	0.8779	0.4824	26.01
857	120	29.91	2.793	3.002	3794.32	27.137	1716.13	1475.93	27.771	31.663	0.8771	0.4825	26.20
858	120	29.91	2.790	2.998	3794.57	27.136	1716.17	1474.69	27.751	31.630	0.8773	0.4828	26.29
859	100	29.91	2.799	2.989	3162.74	27.893	1470.31	1850.32	28.234	31.712	0.8903	0.4029	16.42
860	100	29.91	2.797	2.987	3161.72	27.892	1469.76	1848.98	28.206	31.700	0.8898	0.4028	16.36
861	100	29.91	2.796	2.985	3161.56	27.886	1469.39	1848.28	28.199	31.684	0.8900	0.4029	16.18
862	80	29.91	2.800	2.992	2537.39	28.082	1187.59	2205.46	26.817	31.728	0.8452	0.3231	13.72
863	80	29.91	2.800	2.991	2537.29	28.076	1187.29	2205.53	26.823	31.727	0.8454	0.3231	13.67
864	80	29.91	2.795	2.986	2535.86	28.082	1186.85	2203.89	26.783	31.680	0.8454	0.3232	13.86
865	100	29.93	3.460	3.820	3159.82	27.979	1473.46	2167.72	32.946	37.168	0.8864	0.3699	13.89
866	100	29.92	3.465	3.824	3159.78	27.978	1473.41	2170.18	32.983	37.203	0.8866	0.3697	13.26
867	100	29.92	3.465	3.824	3160.46	27.978	1473.72	2169.33	32.978	37.204	0.8864	0.3698	13.26
871	100	29.89	2.456	2.592	3159.53	27.678	1457.50	1631.65	25.065	28.187	0.8892	0.4274	21.57
872	100	29.89	2.455	2.591	3159.83	27.675	1457.46	1630.62	25.055	28.171	0.8894	0.4275	21.70
873	100	29.89	2.455	2.592	3159.44	27.680	1457.54	1631.37	25.059	28.177	0.8893	0.4274	21.87
874	120	29.88	2.429	2.587	3793.48	26.722	1689.47	1259.86	24.069	27.886	0.8631	0.5136	33.71
875	120	29.88	2.428	2.586	3792.94	26.712	1688.65	1258.86	24.055	27.873	0.8630	0.5136	33.70
876	120	29.88	2.430	2.586	3794.83	26.709	1689.25	1259.84	24.089	27.897	0.8635	0.5137	33.72
877	80	29.85	2.459	2.589	2526.57	28.082	1182.53	1994.55	24.149	28.220	0.8557	0.3420	13.97
878	80	29.85	2.461	2.590	2527.41	28.083	1182.94	1996.60	24.182	28.240	0.8563	0.3420	13.83
879	80	29.85	2.459	2.588	2527.04	28.083	1182.78	1994.48	24.152	28.218	0.8559	0.3421	13.58
880	80	29.89	2.104	2.187	2526.85	27.912	1175.51	1704.78	20.769	23.829	0.8716	0.3727	17.15
881	80	29.88	2.103	2.186	2527.30	27.920	1176.04	1704.59	20.764	23.820	0.8717	0.3729	17.05
882	80	29.89	2.103	2.186	2527.91	27.914	1176.06	1704.84	20.777	23.823	0.8722	0.3729	17.21
883	100	29.91	2.094	2.189	3163.08	26.981	1422.38	1318.17	20.796	23.696	0.8776	0.4663	30.32
884	100	29.90	2.095	2.189	3163.50	26.977	1422.38	1317.58	20.792	23.706	0.8771	0.4663	30.22
885	100	29.90	2.094	2.189	3161.65	26.980	1421.67	1318.60	20.795	23.693	0.8777	0.4661	30.39
886	120	29.90	2.069	2.189	3791.06	25.853	1633.49	988.79	19.513	23.354	0.8355	0.5588	42.61
887	120	29.90	2.069	2.189	3790.39	25.837	1632.20	987.35	19.493	23.349	0.8348	0.5588	42.58

Table VII. Reduced Test Data and Calculated Performance Parameters - Configuration 7 (PPPPLP) (Continued).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
888	120	29.90	2.068	2.188	3791.35	25.838	1632.67	986.73	19.485	23.341	0.8348	0.5590	42.62
889	100	19.92	3.423	3.771	3162.30	27.933	1472.23	2137.18	32.560	36.898	0.8824	0.3716	14.95
890	100	19.93	3.437	3.788	3161.95	27.921	1471.42	2139.82	32.611	37.004	0.8813	0.3711	13.44
891	100	19.93	3.440	3.790	3161.30	27.924	1471.26	2140.74	32.615	37.023	0.8809	0.3709	13.25
892	100	19.93	3.441	3.795	3168.51	27.921	1474.46	2140.04	32.682	37.035	0.8825	0.3716	14.13
893	100	19.93	3.447	3.800	3180.58	27.928	1480.47	2133.13	32.692	37.073	0.8818	0.3729	13.4
894	100	19.93	3.446	3.802	3163.97	27.937	1473.21	2142.74	32.657	37.064	0.8811	0.3709	14.14
895	120	19.93	3.454	3.806	3797.78	27.361	1731.88	1760.40	32.882	37.129	0.8856	0.4450	16.95
896	120	19.93	3.460	3.812	3799.01	27.359	1732.28	1759.78	32.884	37.166	0.8848	0.4450	16.55
897	120	19.93	3.459	3.810	3799.49	27.360	1732.56	1758.63	32.866	37.159	0.8845	0.4451	16.45
898	90	19.95	3.419	3.775	2850.15	28.020	1331.00	2320.89	31.770	36.870	0.8617	0.3348	14.89
899	90	19.95	3.416	3.772	2851.55	28.031	1332.18	2320.48	31.768	36.850	0.8621	0.3351	14.97
900	90	19.95	3.415	3.771	2851.51	28.031	1332.17	2320.23	31.763	36.843	0.8621	0.3351	14.90
901	80	19.92	3.119	3.394	2530.74	28.066	1183.79	2371.80	28.781	34.545	0.8331	0.3078	16.06
902	80	19.92	3.112	3.383	2527.40	28.055	1181.79	2366.71	28.692	34.482	0.8321	0.3077	15.6
903	80	19.92	3.110	3.380	2532.11	28.058	1184.12	2364.83	28.720	34.463	0.8333	0.3084	15.65
904	90	34.87	3.449	3.817	2850.72	28.087	1334.45	2353.05	32.140	37.087	0.8666	0.3337	15.15
905	90	34.85	3.444	3.811	2850.46	28.088	1334.41	2353.08	32.136	37.052	0.8673	0.3339	15.12
906	90	34.86	3.445	3.812	2849.11	28.086	1333.66	2352.76	32.119	37.059	0.8667	0.3337	15.20
907	100	34.87	3.457	3.815	3157.82	28.020	1474.69	2174.32	32.977	37.150	0.8877	0.3698	13.21
908	100	34.87	3.457	3.815	3158.04	28.019	1474.75	2174.79	32.987	37.145	0.8881	0.3698	13.30
909	100	34.86	3.455	3.812	3156.95	28.020	1474.28	2174.03	32.963	37.133	0.8877	0.3698	13.16
910	110	34.86	3.472	3.828	3473.27	27.821	1610.50	1984.88	33.347	37.254	0.8951	0.4063	13.45
911	110	34.86	3.462	3.815	3471.55	27.829	1610.14	1982.84	33.287	37.181	0.8953	0.4065	13.60
912	110	34.86	3.455	3.806	3472.51	27.828	1610.55	1979.96	33.249	37.133	0.8954	0.4069	13.45
913	99	39.84	3.461	3.822	3152.02	28.056	1473.89	2183.64	33.014	37.176	0.8881	0.3689	13.30
914	100	39.84	3.464	3.825	3161.00	28.048	1477.68	2179.13	33.049	37.195	0.8885	0.3699	13.29
915	100	39.84	3.460	3.820	3161.16	28.048	1477.74	2178.01	33.034	37.166	0.8888	0.3700	13.41
916	109	39.83	3.472	3.829	3466.84	27.861	1609.82	1992.89	33.372	37.252	0.8958	0.405	13.55
917	109	39.82	3.463	3.818	3466.26	27.874	1610.32	1991.44	33.326	37.191	0.8961	0.4058	13.53
918	109	39.84	3.474	3.832	3466.17	27.865	1609.73	1994.88	33.394	37.272	0.8959	0.4053	13.30
919	95	39.90	3.455	3.817	3018.15	28.087	1412.87	2260.23	32.684	37.131	0.8803	0.3534	13.71
920	95	39.90	3.458	3.821	3017.65	28.085	1412.53	2261.74	32.703	37.154	0.8802	0.3532	13.67
921	95	39.90	3.457	3.820	3016.95	28.086	1412.21	2261.67	32.694	37.148	0.8801	0.3531	13.6
923	80	20.00	3.424	3.810	2529.32	28.052	1182.53	2515.22	30.520	36.904	0.8270	0.2963	19.05
924	80	20.00	3.436	3.821	2533.48	28.055	1184.61	2514.81	30.561	36.995	0.8261	0.2965	18.09
926	80	20.01	3.483	3.888	2533.83	28.047	1184.46	2531.98	30.783	37.336	0.8245	0.2950	18.42
927	80	20.01	3.482	3.889	2534.02	28.057	1184.94	2534.03	30.800	37.330	0.8251	0.2950	18.66
929	100	29.91	3.863	4.385	3160.51	28.000	1474.89	2315.35	35.170	39.874	0.8820	0.3555	14.62
930	100	29.92	3.870	4.396	3161.66	28.006	1475.76	2318.52	35.223	39.920	0.8823	0.3554	14.59
931	100	29.92	3.949	4.515	3160.39	28.013	1475.51	2342.54	35.566	40.403	0.8803	0.3527	15.02
932	100	29.92	3.950	4.521	3160.11	28.018	1475.69	2346.33	35.613	40.414	0.8812	0.3526	15.37
934	100	29.92	3.649	4.078	3156.22	28.017	1473.80	2243.39	34.010	38.487	0.8837	0.362	13.66
935	100	29.93	3.649	4.079	3157.89	28.019	1474.69	2243.60	34.029	38.488	0.8841	0.3625	13.84
936	100	29.93	3.648	4.079	3159.48	28.014	1475.17	2244.70	34.069	38.478	0.8854	0.3627	14.44
938	120	29.89	3.657	4.072	3790.99	27.510	1738.16	1854.05	34.383	38.538	0.8922	0.4354	14.75
939	120	29.88	3.661	4.079	3791.69	27.512	1738.61	1855.60	34.416	38.567	0.8924	0.4352	14.99
940	100	29.93	3.465	3.827	3160.84	28.008	1475.49	2171.67	32.982	37.201	0.8866	0.3698	13.96
941	100	29.93	3.462	3.823	3160.70	28.017	1475.87	2171.35	32.965	37.182	0.8866	0.3699	13.62
942	100	29.93	3.465	3.827	3161.66	28.013	1476.13	2171.85	32.987	37.204	0.8867	0.3699	13.57

Table VII. Reduced Test Data and Calculated Performance Parameters - Configuration 7 (PPPPLP) (Concluded).

RDG	PCT NDES	PT0	PT0/PT3	PT0/PS3	N EQV	WA EQV	WAN EQV	TQ EQV	DH EQV	DHI EQV	ETA TT	U/C0	FLOWANG
943	100	29.88	1.939	2.021	3160.91	26.437	1392.77	1163.79	18.725	21.451	0.8729	0.4891	35.24
944	100	29.88	1.938	2.020	3161.24	26.442	1393.15	1163.02	18.712	21.443	0.8726	0.4892	35.25
945	100	29.88	1.937	2.019	3160.67	26.444	1392.99	1162.70	18.702	21.430	0.8727	0.489	35.24
946	100	29.88	1.680	1.745	3162.38	24.791	1306.64	844.31	14.494	17.144	0.8454	0.5444	45.36
947	100	29.86	1.678	1.744	3162.23	24.800	1307.07	843.63	14.476	17.122	0.8455	0.5447	45.37
948	100	29.86	1.678	1.743	3162.71	24.815	1308.04	844.93	14.492	17.113	0.8469	0.5449	45.37

TABLE VIII. OVERALL AND STAGE PERFORMANCE SUMMARY

a. Overall Performance

Stage(s)	Configuration	Equivalent Specific Work, E/θ_{cr}	Total-to-Total Pressure Ratio	Total-to-Total Efficiency, η_{TT}
1	3 - PP	13.76	1.604	0.875
1+2	2 - PPPP	26.38	2.66	0.868
1+2	4 - PPTP	26.78	2.66	0.880
1+2+3	1 - PPPPPP	33.00	3.47	0.886
1+2+3	5 - PPPPPT	32.97	3.47	0.885
1+2+3	6 - PPTPTT	32.90	3.47	0.883
1+2+3	7 - PPPPLP	33.00	3.47	0.886

b. Stage Performance

Stage	Stage Configuration	Stage Equivalent Specific Work, E/θ_{cr}	Stage Total-to-Total Pressure	Stage Total-to-Total Efficiency, η_{TT}
1	PP/	13.76	1.604	0.875
2	/PP/	12.62	1.658	0.846
2	/PT/	13.02	1.658	0.873
3	/PP	6.62	1.305	0.923
3	/PT	6.62	1.305	0.918
3	/TT	6.12	1.305	0.856
3	/LP	6.62	1.305	0.923

Key: P - Plain Bladerow   T - Tandem Bladerow   L - Leaned Bladerow

Table IX. Plain Blade Turbine Fatigue Endurance Test Results.

Fixed Hub, Free Tip Boundary Conditions, First Flexural Mode

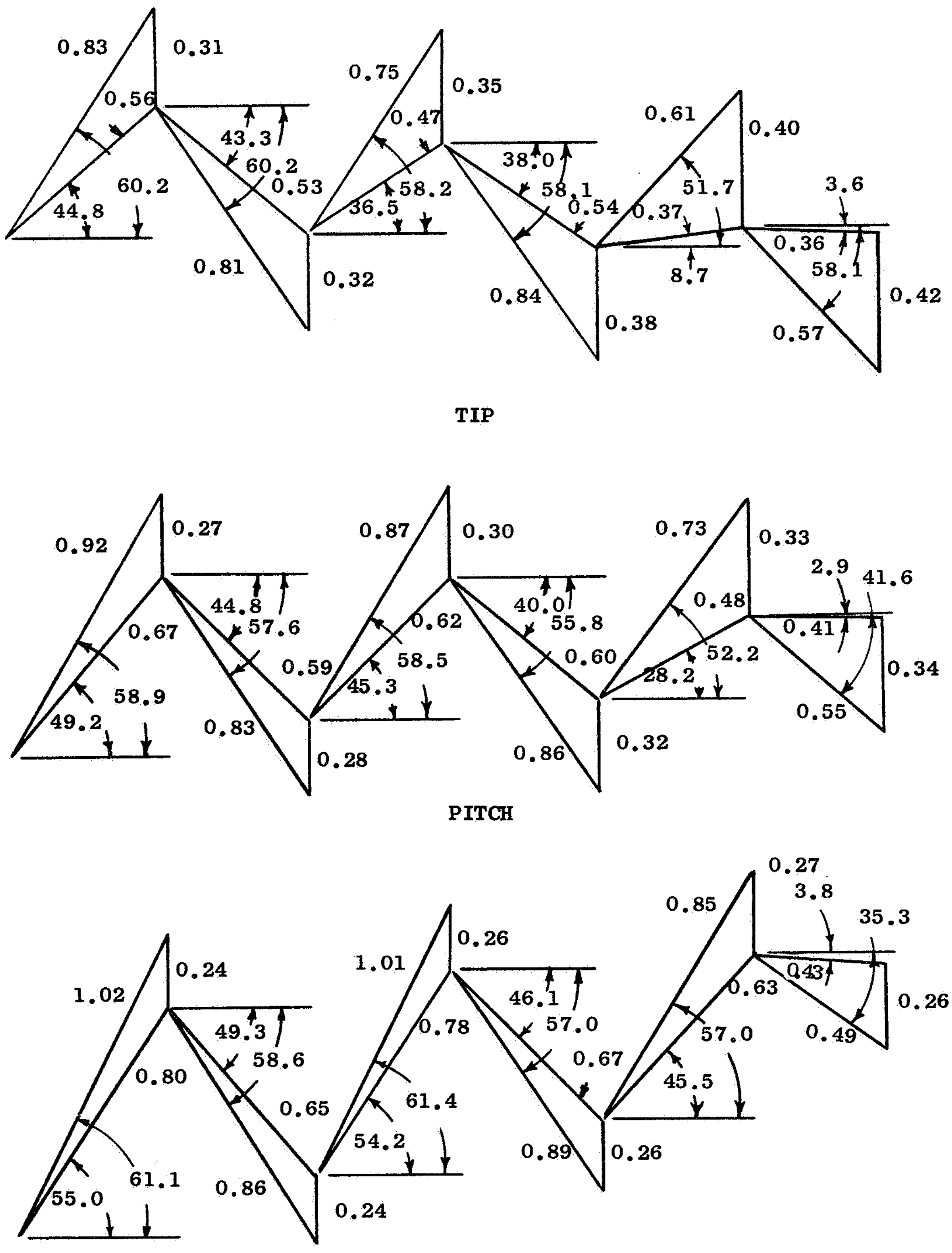
Stage	Serial Number	Blade Frequency	Maximum Gage Stress at Failure*	Cycles	Failure Location
1	113	577 cps	50 ksi-sa 60**	1,000,000 86,000	Run Out Hub Suction Surface "Hi-C"
	116	567	60	340,200	Hub Trailing Edge at fillet
2	103	329 cps	70 ksi-sa	118,440	Hub Trailing Edge, 0.32" above fillet
	109	324	91	77,760	Hub Trailing Edge, 0.37" above fillet
	110	330	60	475,200	Hub Trailing Edge, 0.27" above fillet
3	114	139 cps	60 ksi-sa 70 80	1,100,000 1,200,000 75,000	Run Out Run Out Hub Trailing Edge, 0.50" above fillet
	115	129	100	51,000	Hub Trailing Edge, 0.30" above fillet
	116	135	70	1,000,000 370,000	Run Out Hub Trailing Edge, 0.40" above fillet

*Each stress tabulated is the maximum stress measured on the blade at the time of failure. In all cases except those noted by ** this maximum stress corresponded to the approximate failure location stress.

Table X. Stage Three Tandem Blade Fatigue Endurance Test Results.

Fixed Hub, Fixed Tip Boundary Conditions, First Flexural Mode

Serial Number	Blade Frequency	Maximum Gage Stress at Failure	Cycles	Comments
Unmachined Specimen No Serial Number	1264 cps	40 ksi-sa	1,000,000	Run Out; frequency dropped as test progressed, perhaps due to poor shroud clamp. Set up again.
			1	Failed at leading edge of Forward Airfoil under tip shroud, immediately upon startup. Failure probably occurred during last part of first run.
100	1207 cps	20 ksi-sa	1,000,000	Run Out.
		25	432,000	Pin braze failed. Rebrazed and setup at 20 ksi-sa.
		20	1,000,000	Failed at leading edge of Forward Airfoil just under tip shroud.
103	1292 cps	20 ksi-sa	1,000,000	Run Out.
		25	1,000,000	Run Out.
		30	117,000	Failed at leading edge of Forward Airfoil just under tip shroud.
120	1264 cps	20 ksi-sa	1,000,000	Run Out.
		25	1,000,000	Run Out
		30	1,000,000	Run Out.
		35	829,000	Pin braze failed. Rebrazed and set up at 30 ksi-sa.
		30	321,000	Failed at leading edge of Forward Airfoil just under tip shroud.



Numbers Shown on Velocity Diagrams are Angles in Degrees and Mach Numbers

Figure 1. Turbine Design Velocity Diagrams.

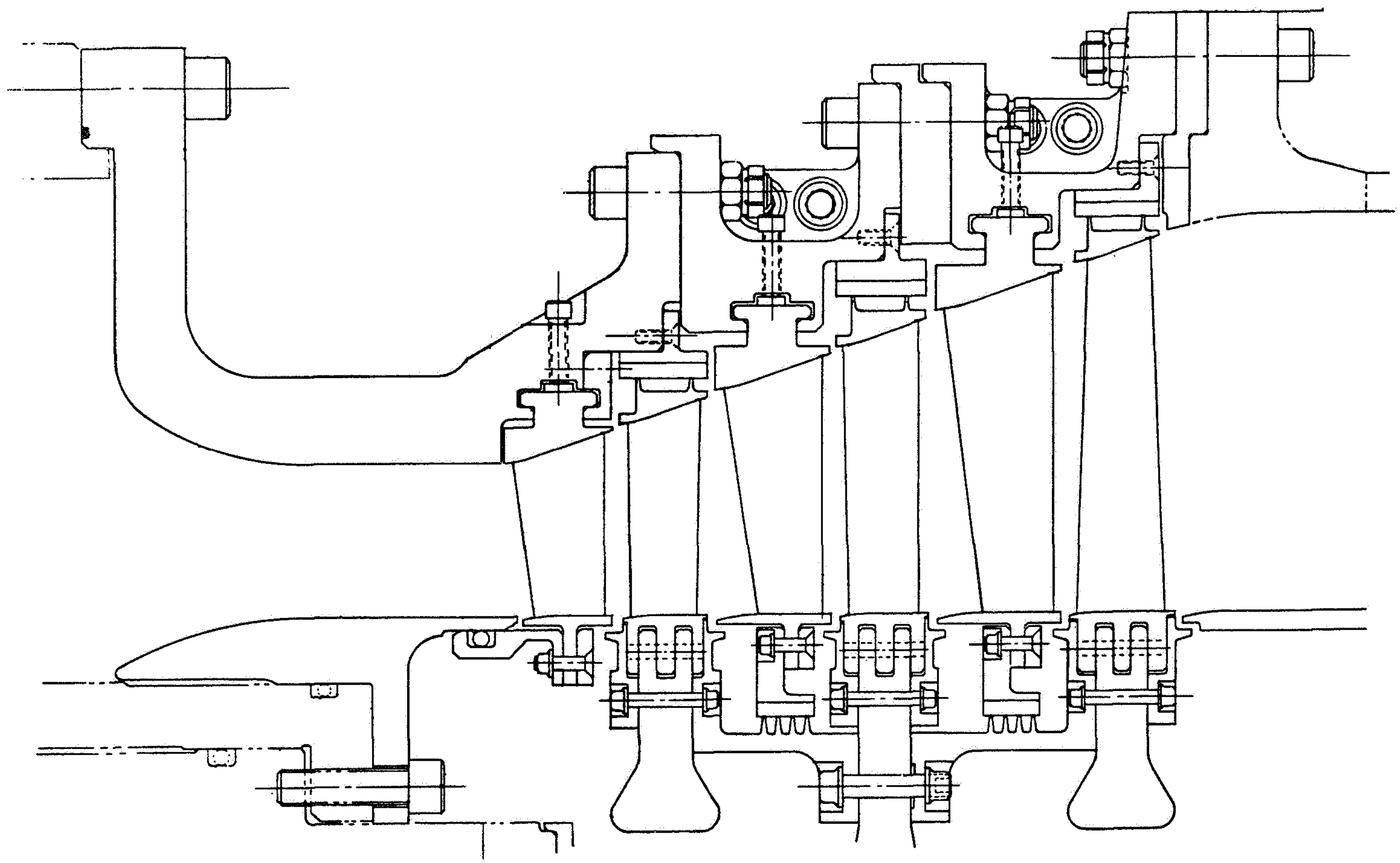


Figure 2. Three-Stage Turbine Flowpath.

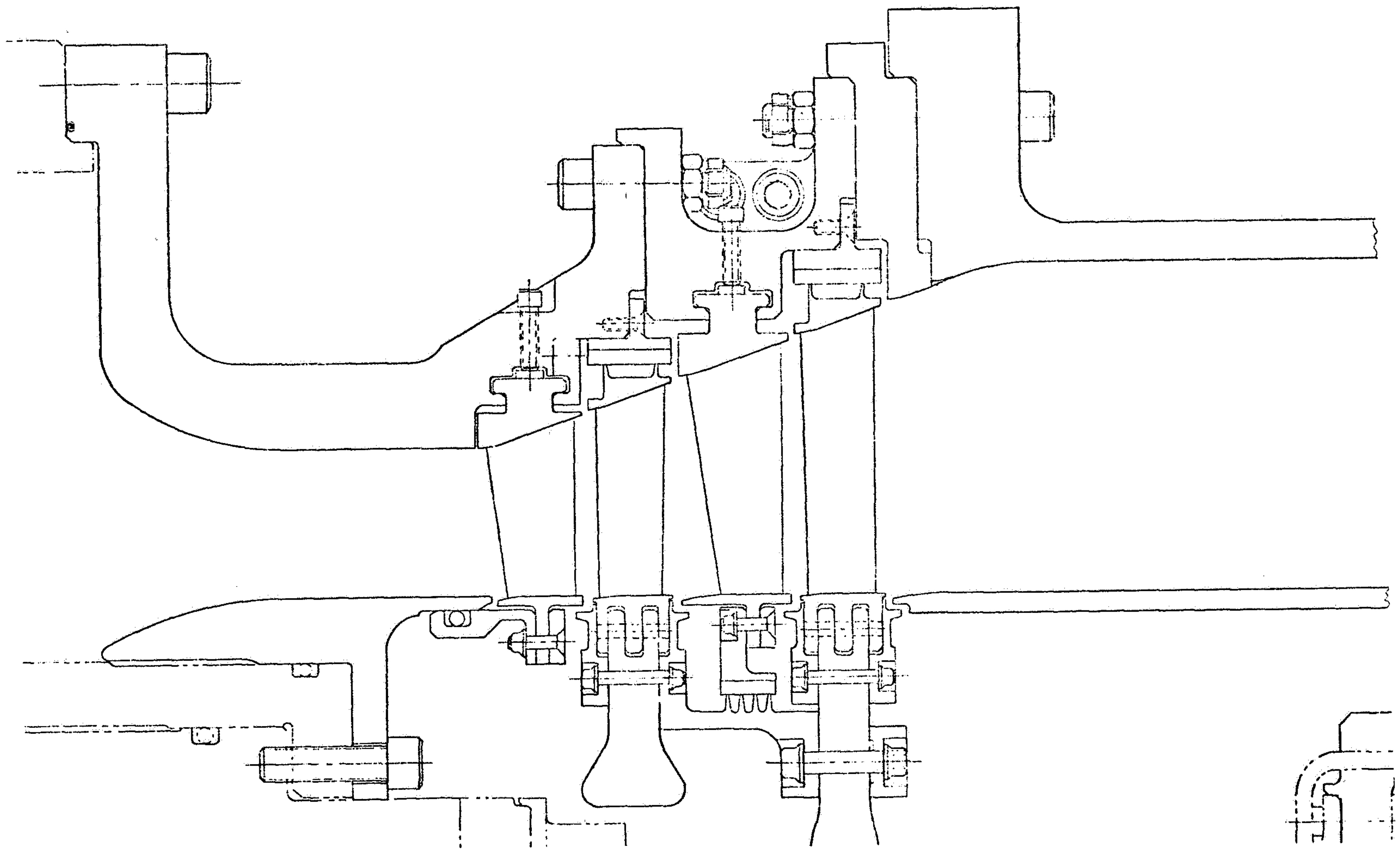


Figure 3. Two-Stage Turbine Flowpath.

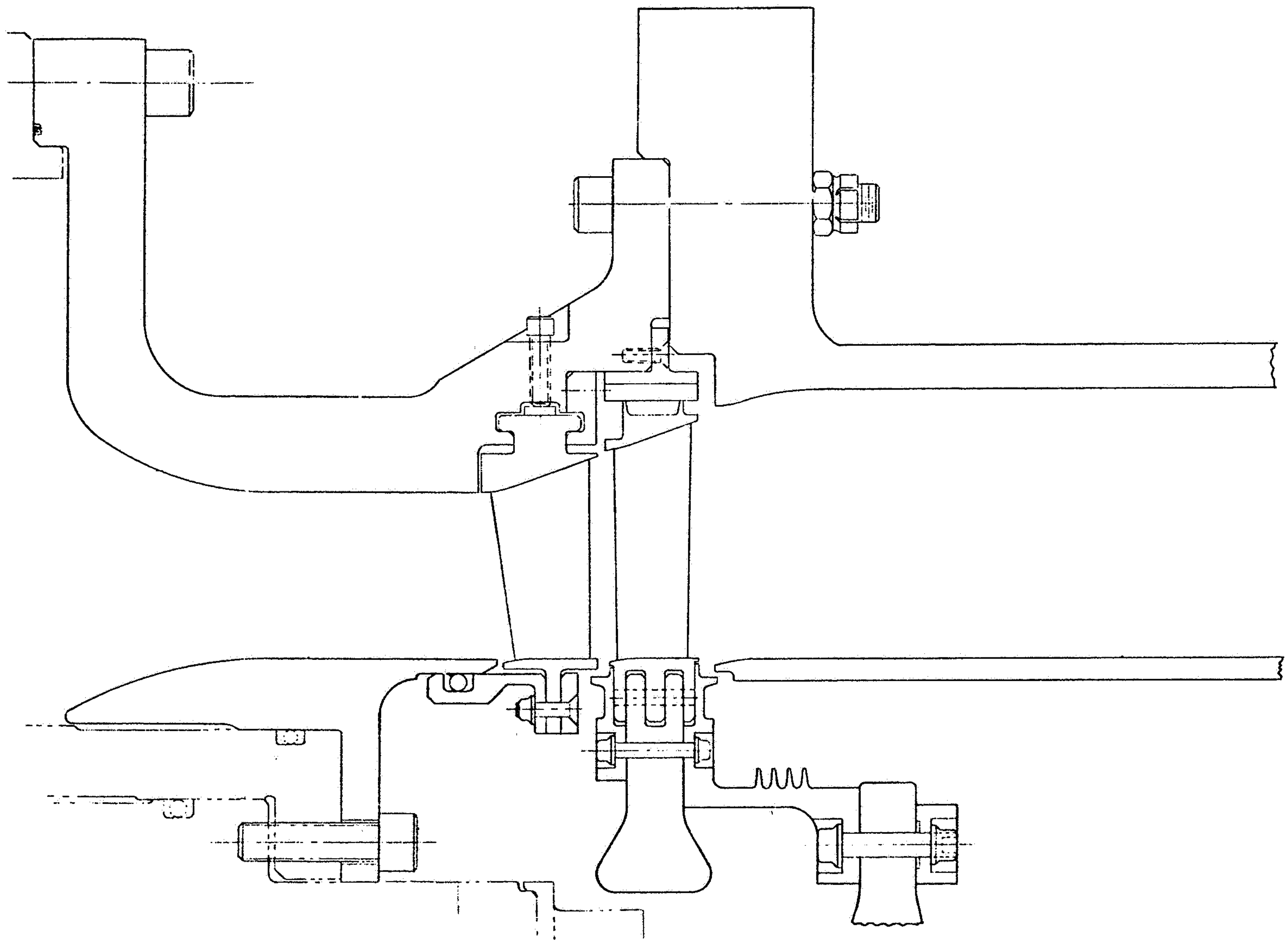


Figure 4. One-Stage Turbine Flowpath.

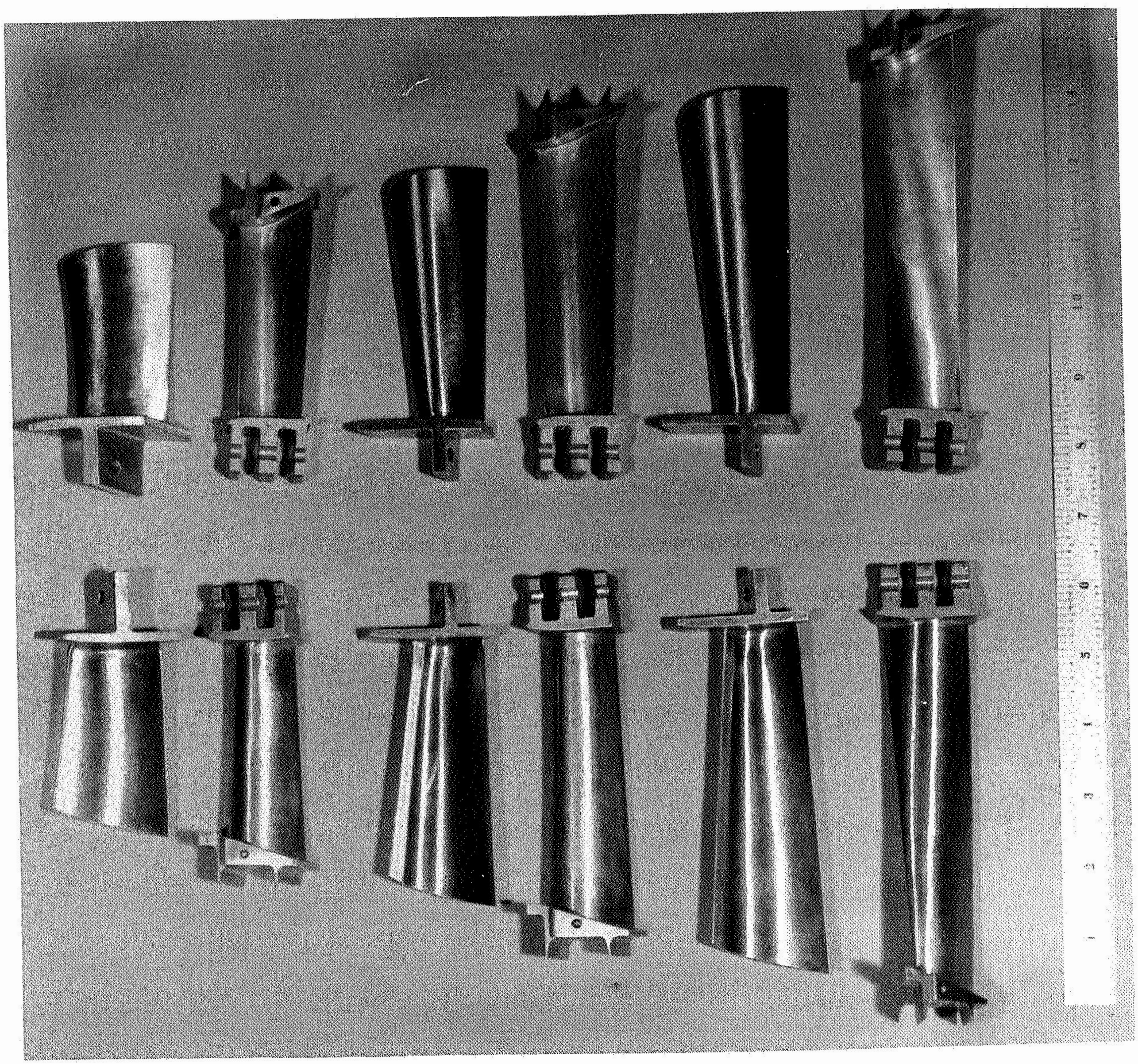


Figure 5. Plain Blade Turbine Airfoils.

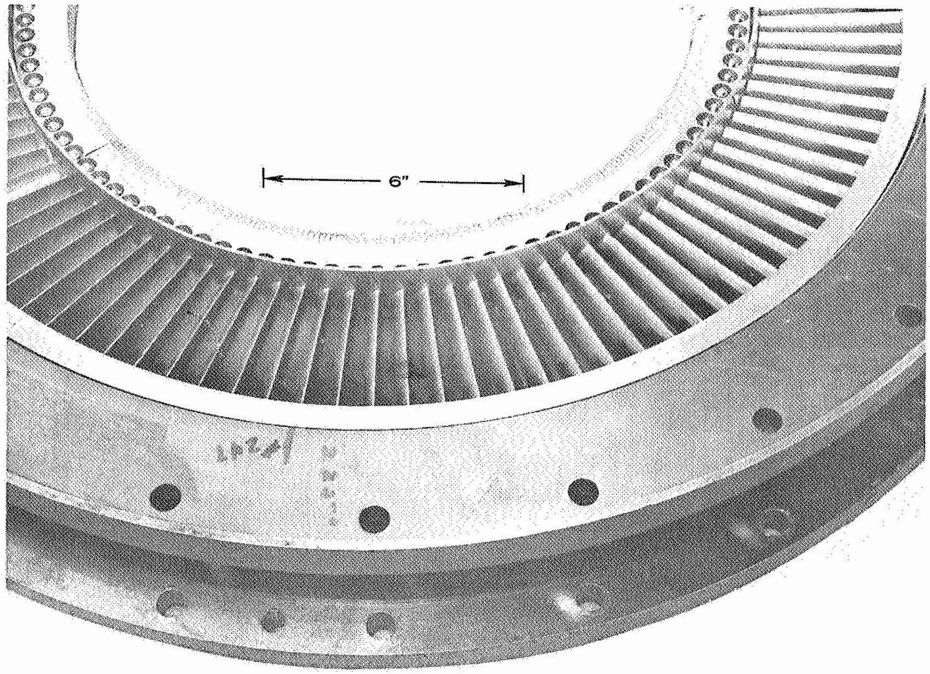


Figure 6. Stage Two Plain Stator Assembled in Outer Casing.

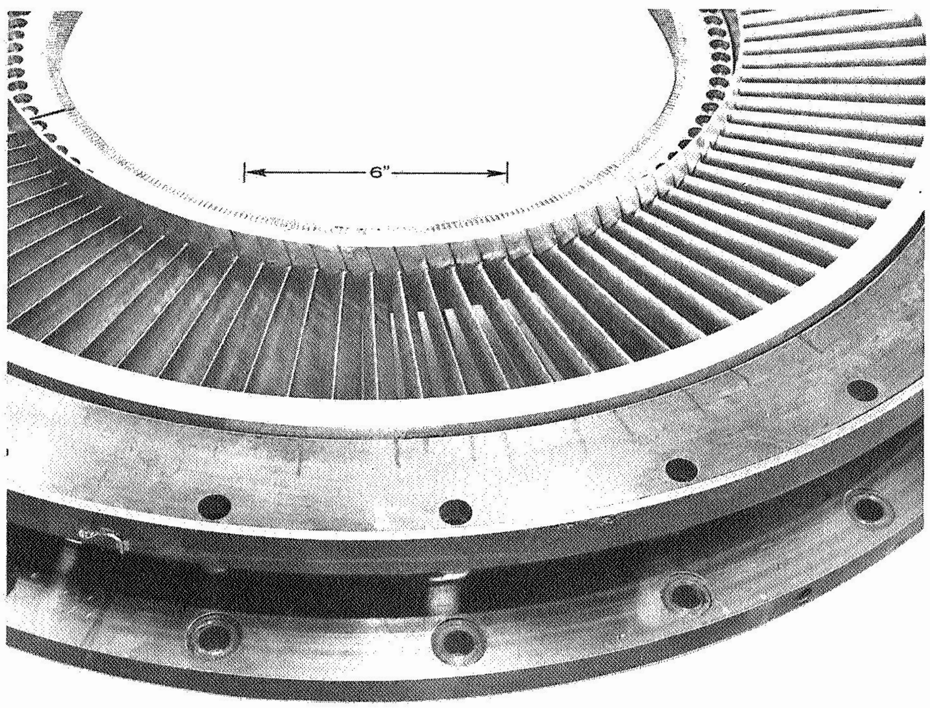


Figure 7. Stage Three Plain Stator Assembled in Outer Casing.

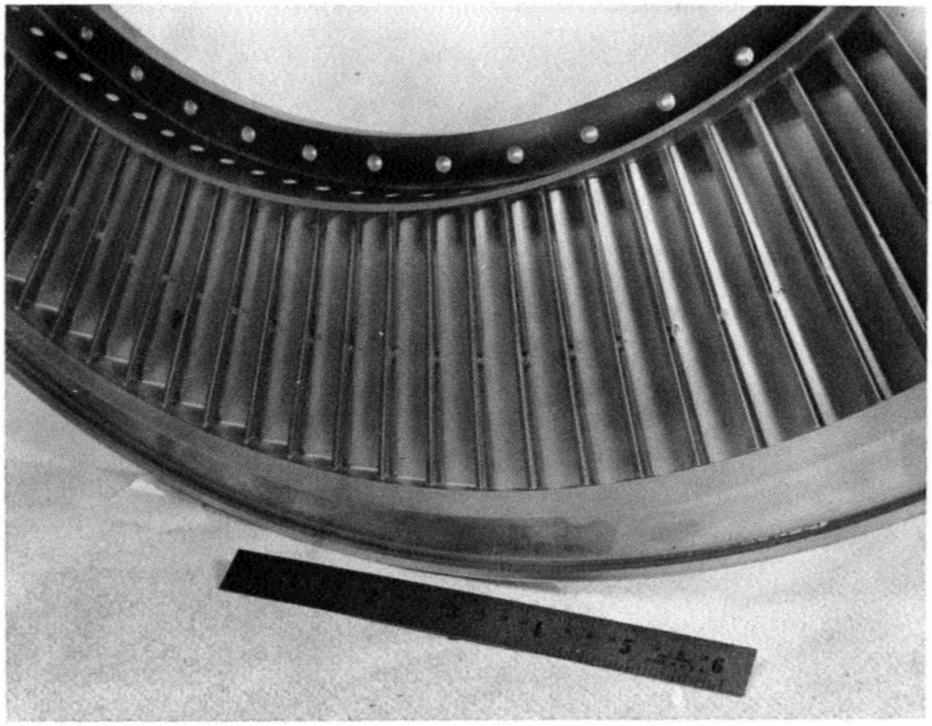


Figure 8. Stage Two Tandem Stator Assembled.

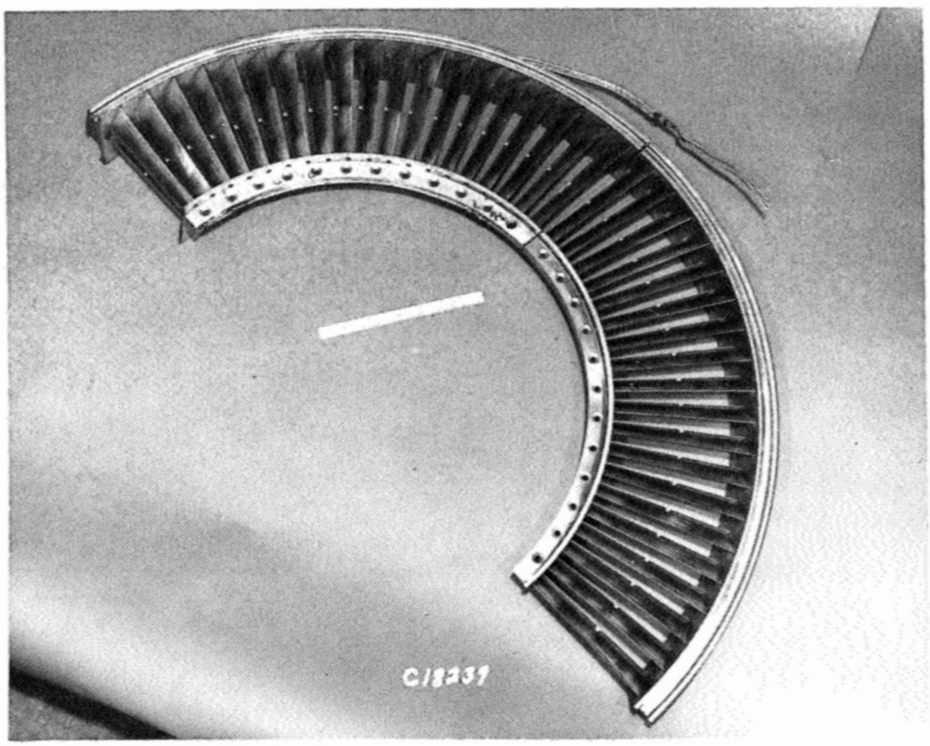


Figure 9. Stage Three Tandem Stator Assembled.

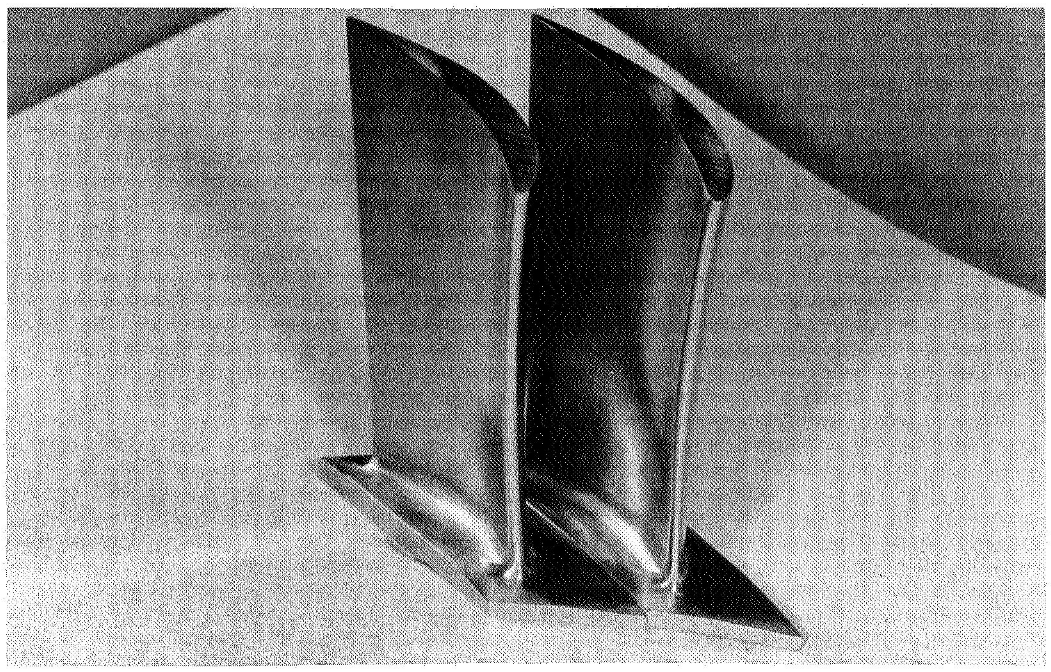


Figure 10. Stage One Plain Stator Airfoils.

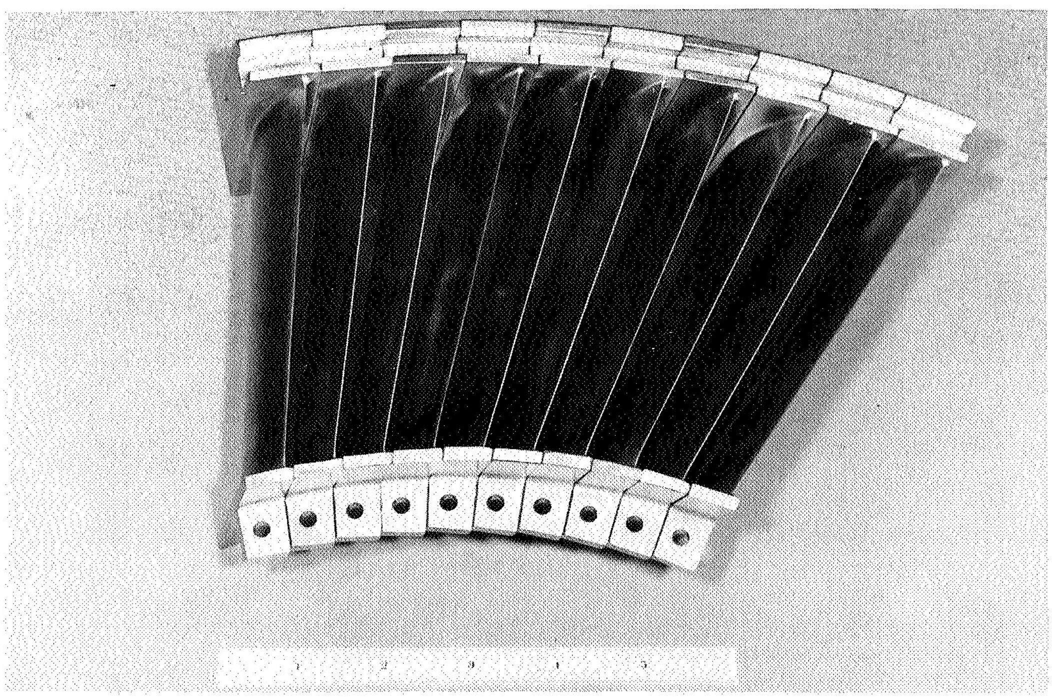


Figure 11. Stage Three Tangentially Leaned Stator Airfoils Viewed Aft Looking Forward.

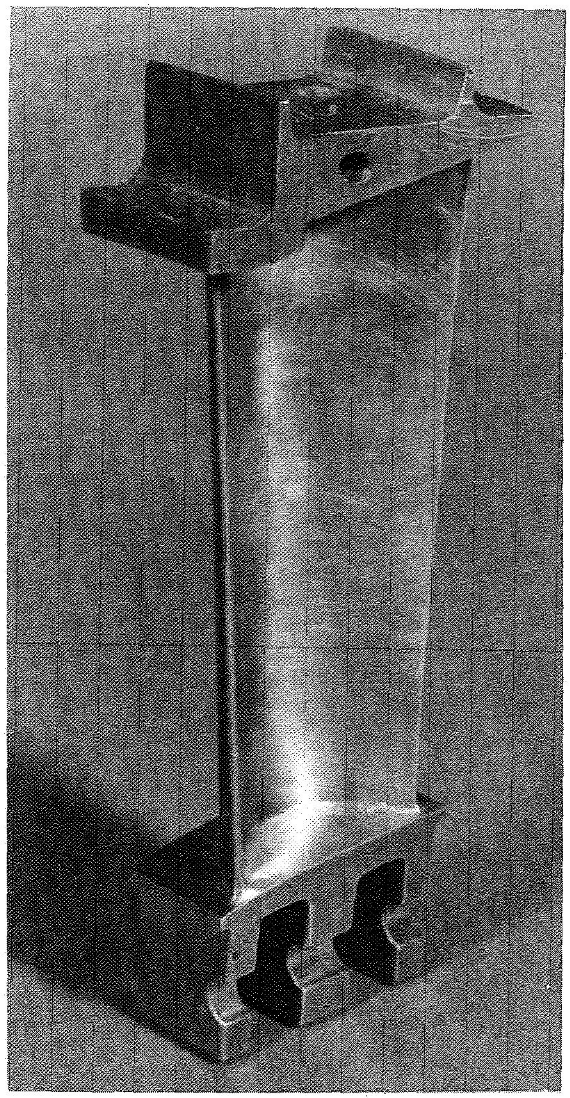


Figure 12. Stage One Rotor Plain Blade.

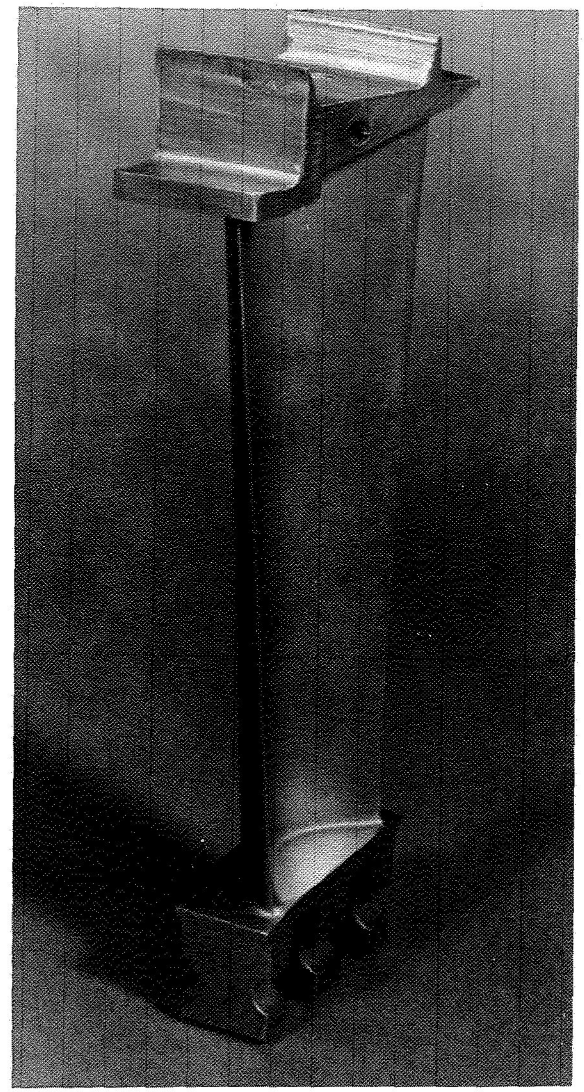


Figure 13. Stage Two Rotor Plain Blade.

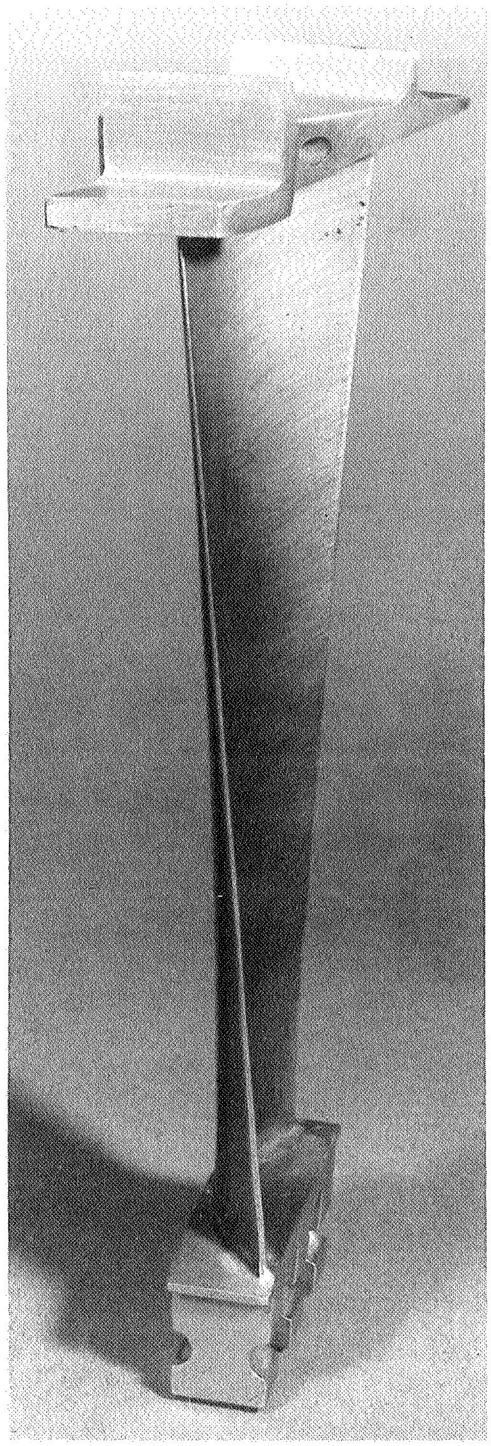


Figure 14. Stage Three Rotor Plain Blade.

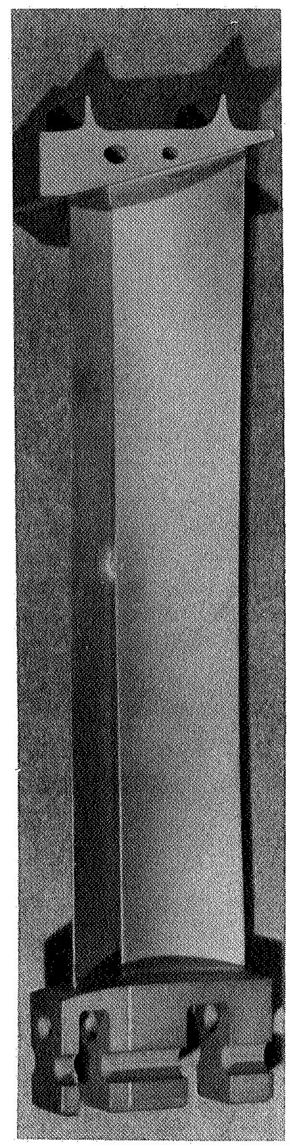


Figure 15. Stage Three Rotor Tandem Blade.

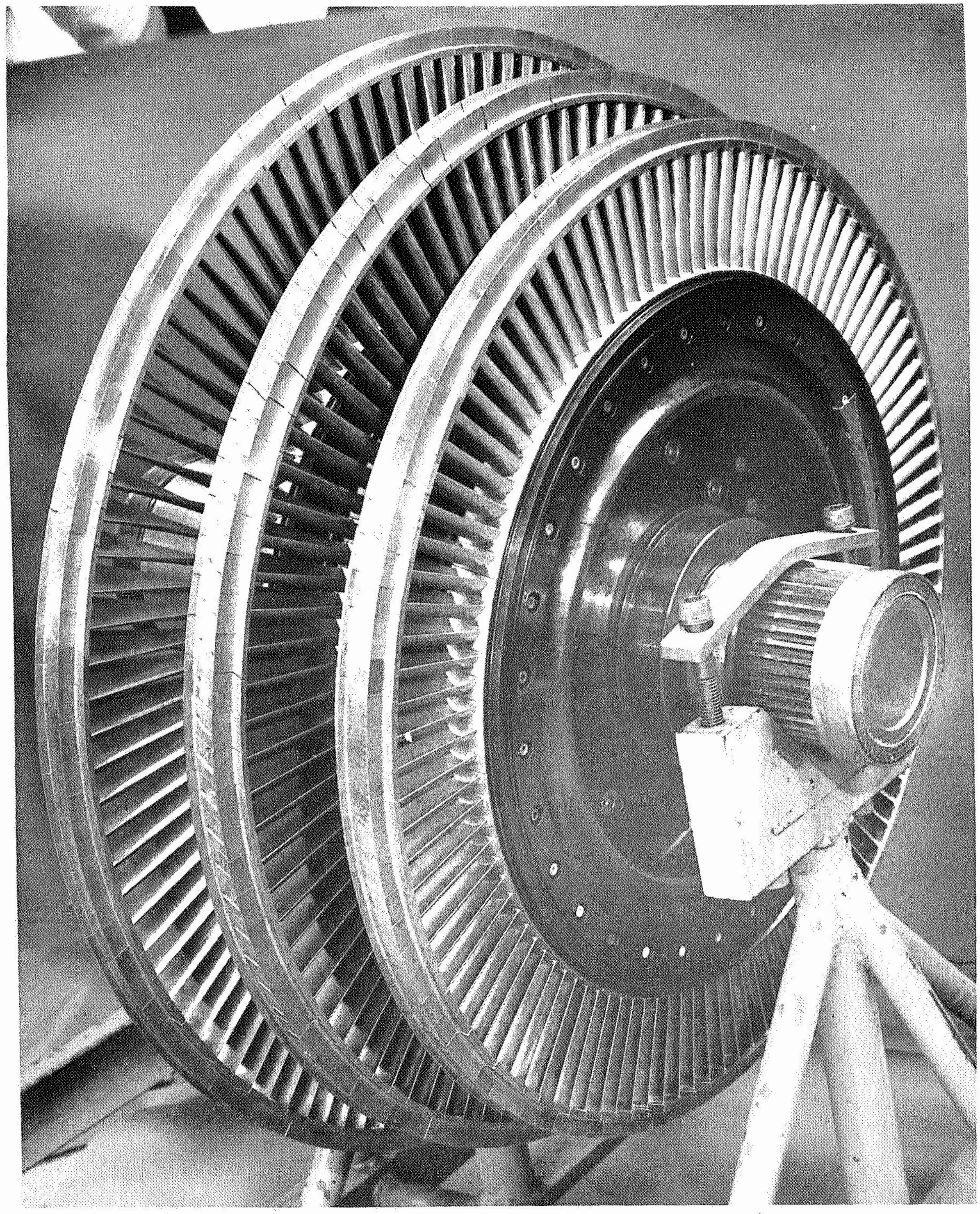


Figure 16. Three-Stage Turbine Plain Blade Rotor Assembled.

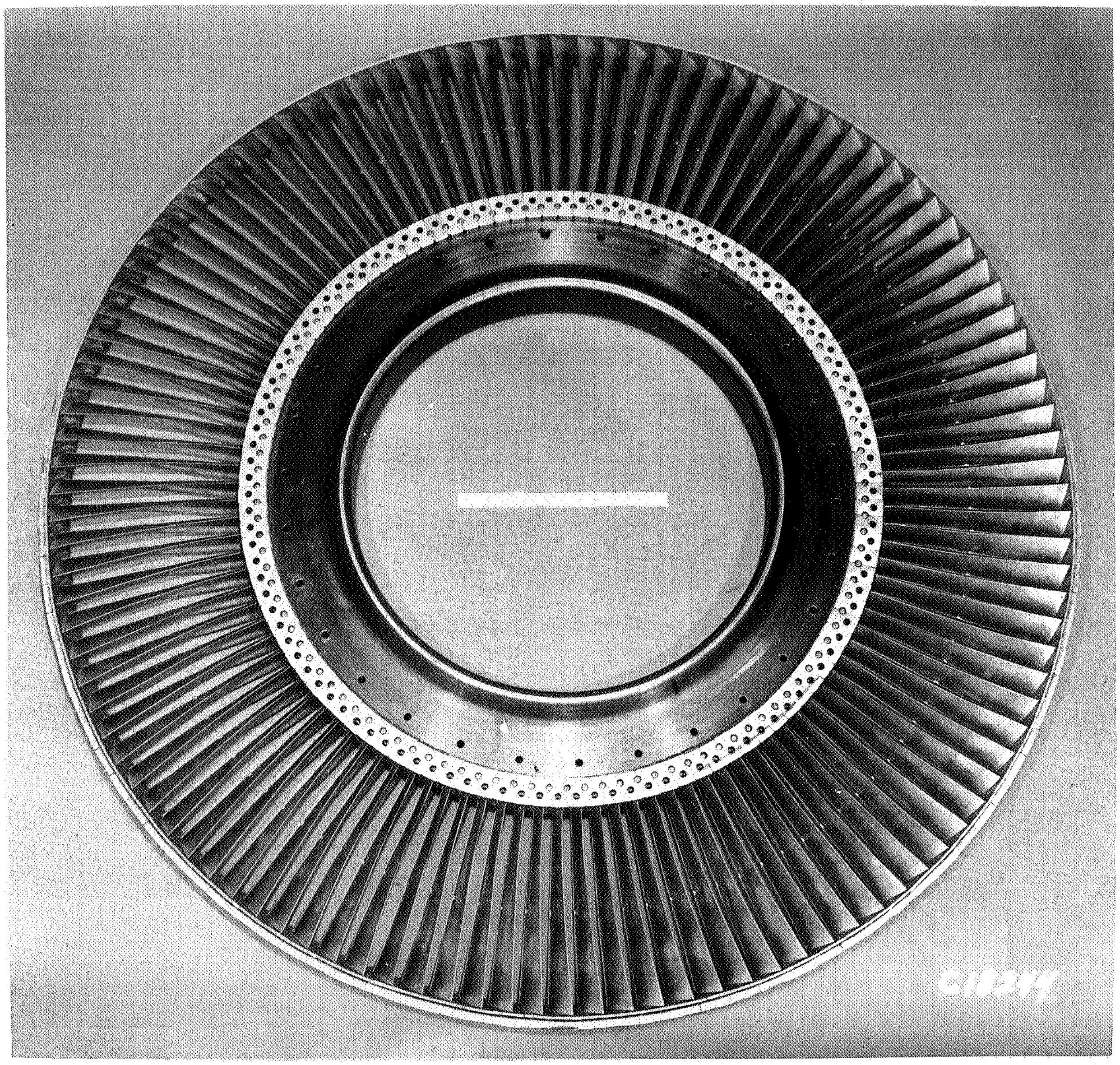


Figure 17. Stage Three Tandem Blade Rotor Assembled.

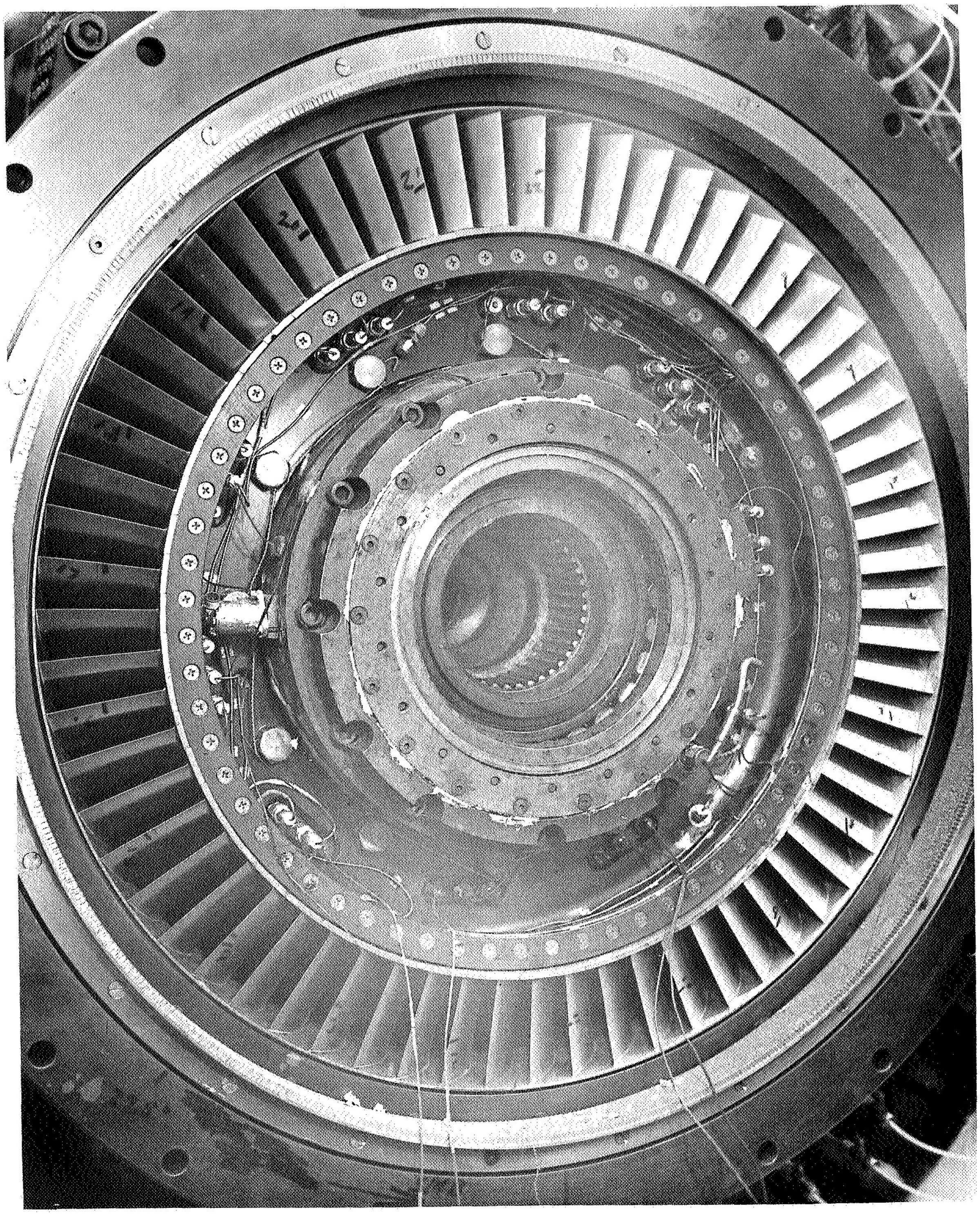


Figure 18. Stage One Stator Installed in Test Facility.

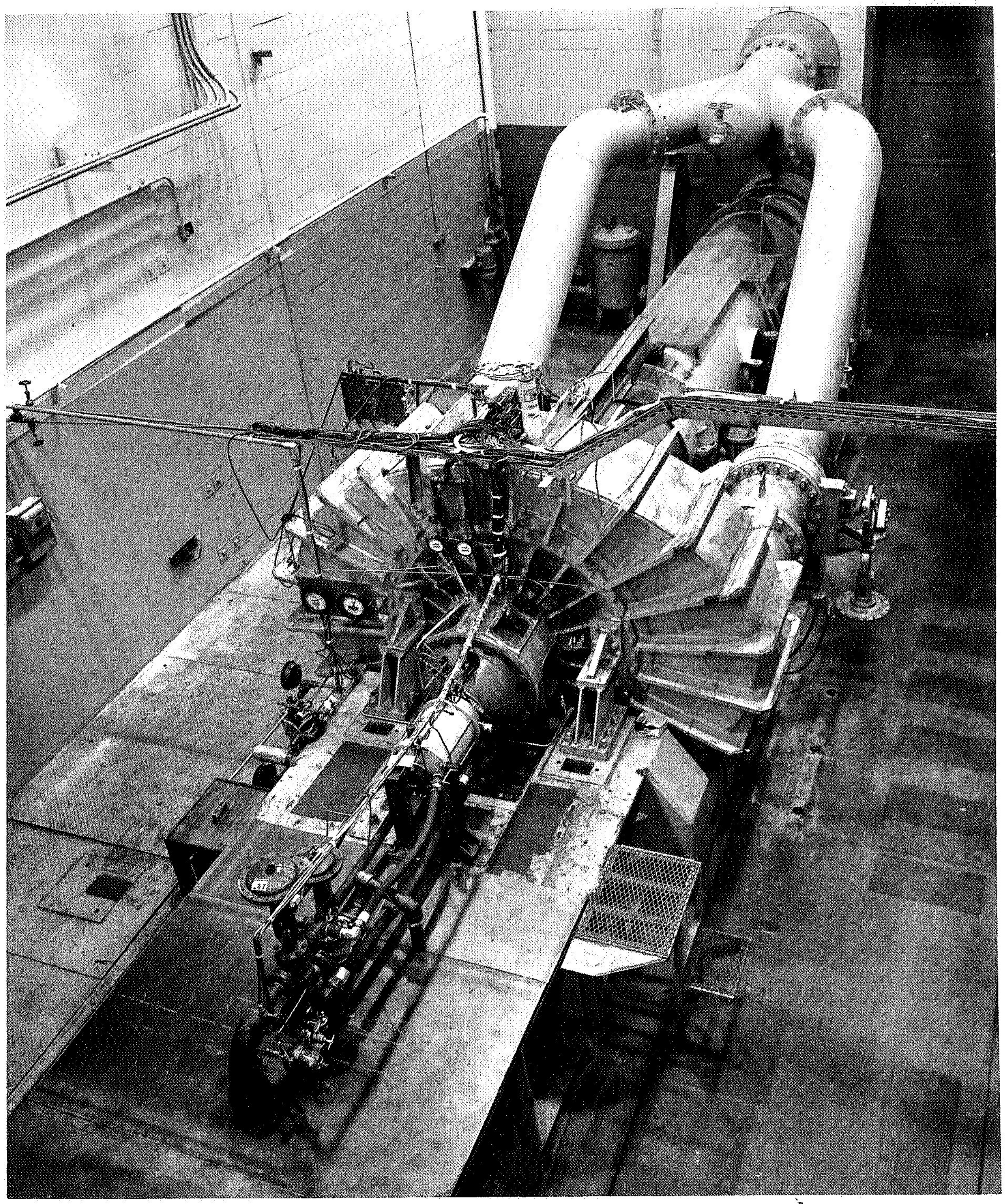


Figure 19. Typical General Electric, Evendale, Air Turbine Test Facility Configuration.

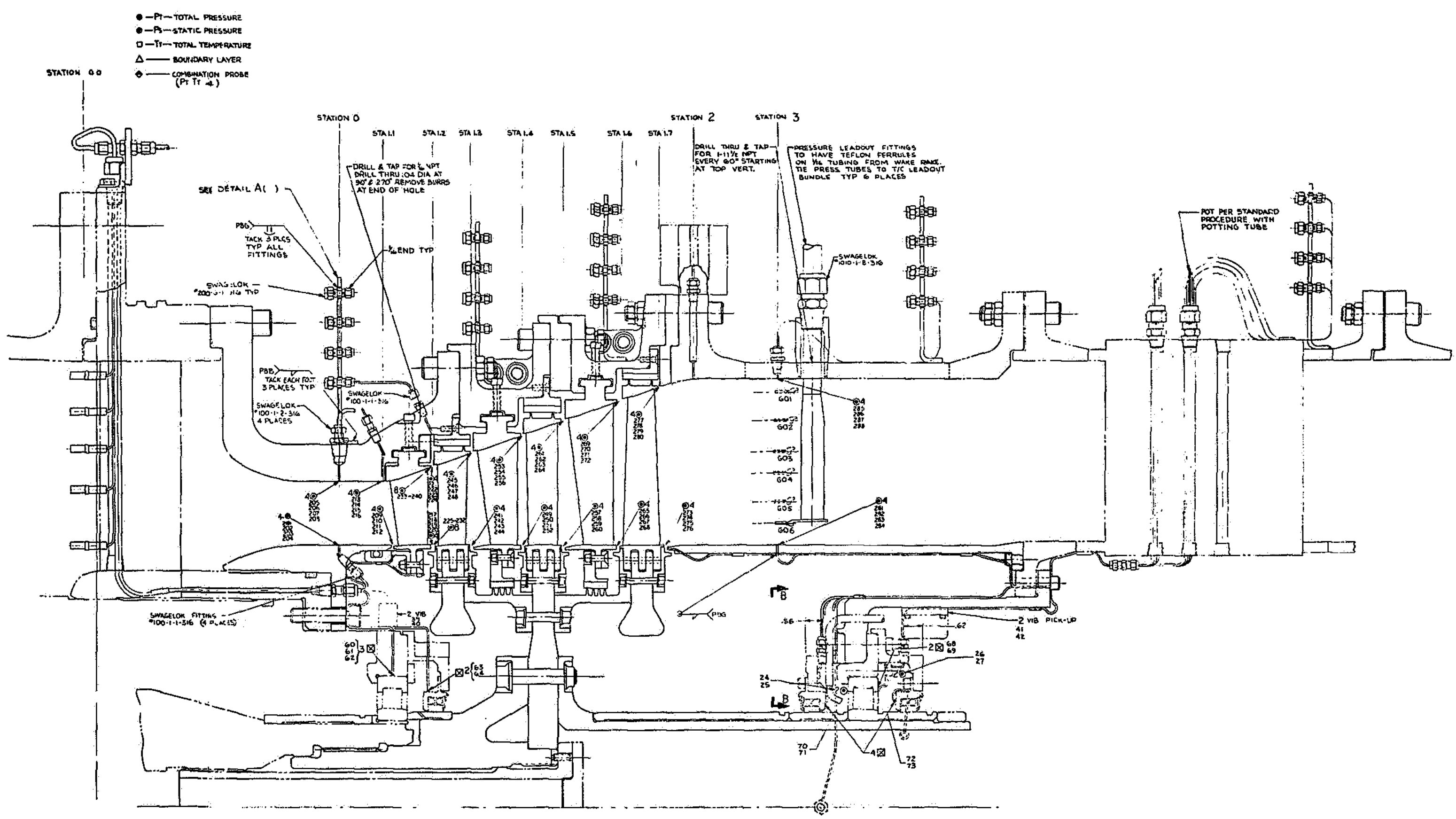


Figure 20. Air Turbine Test Instrumentation.

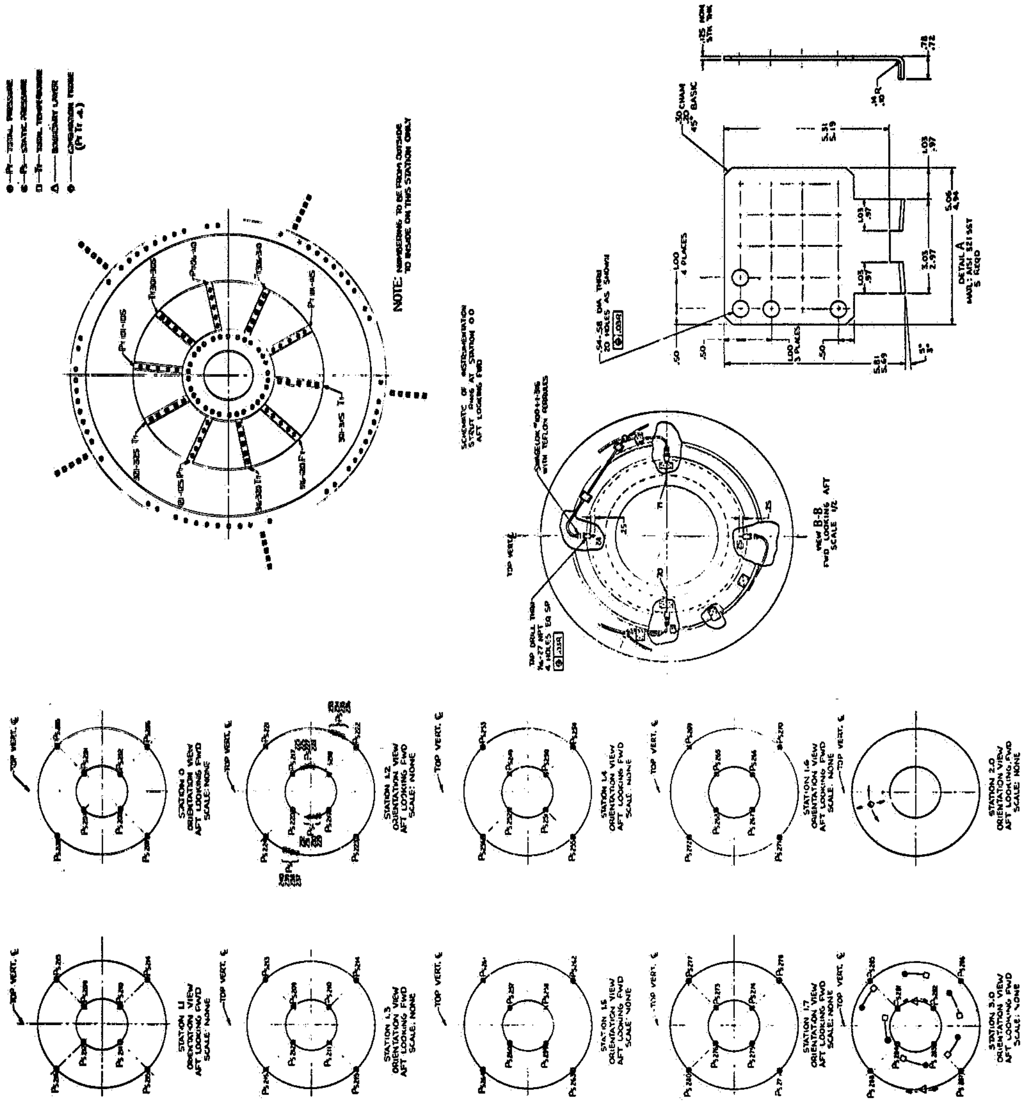


Figure 20. Air Turbine Test Instrumentation (Concluded).

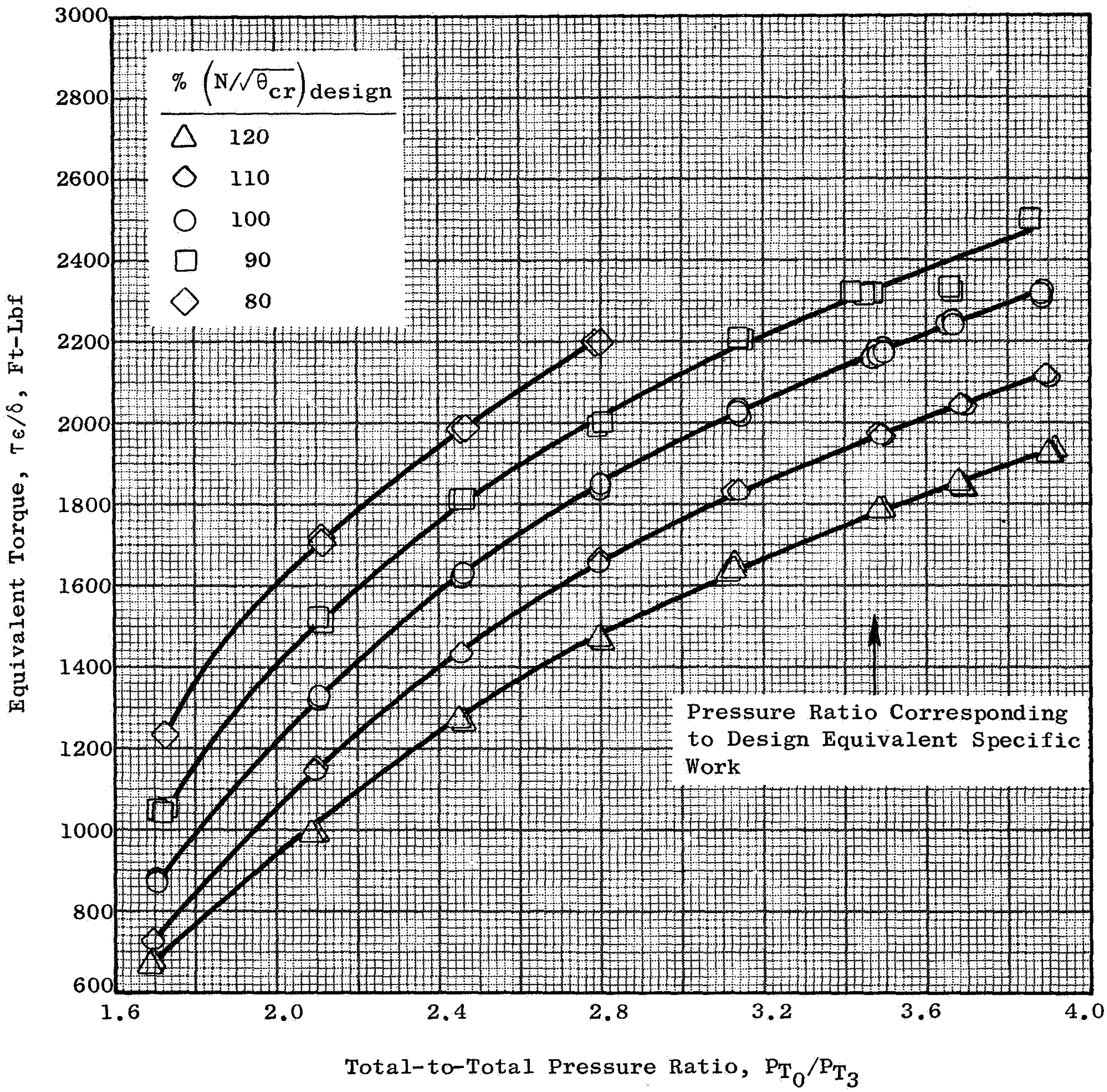


Figure 21. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

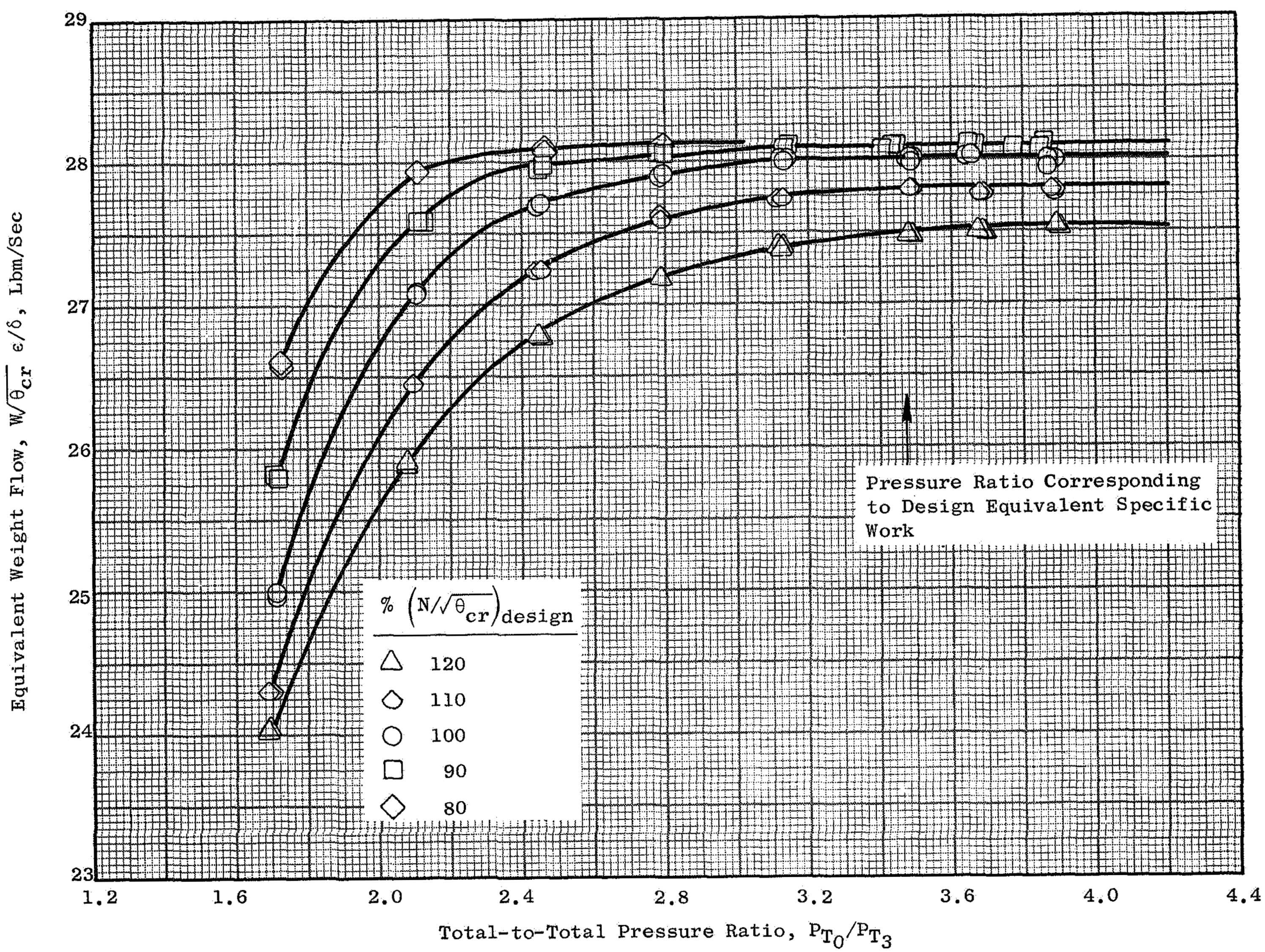


Figure 22. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

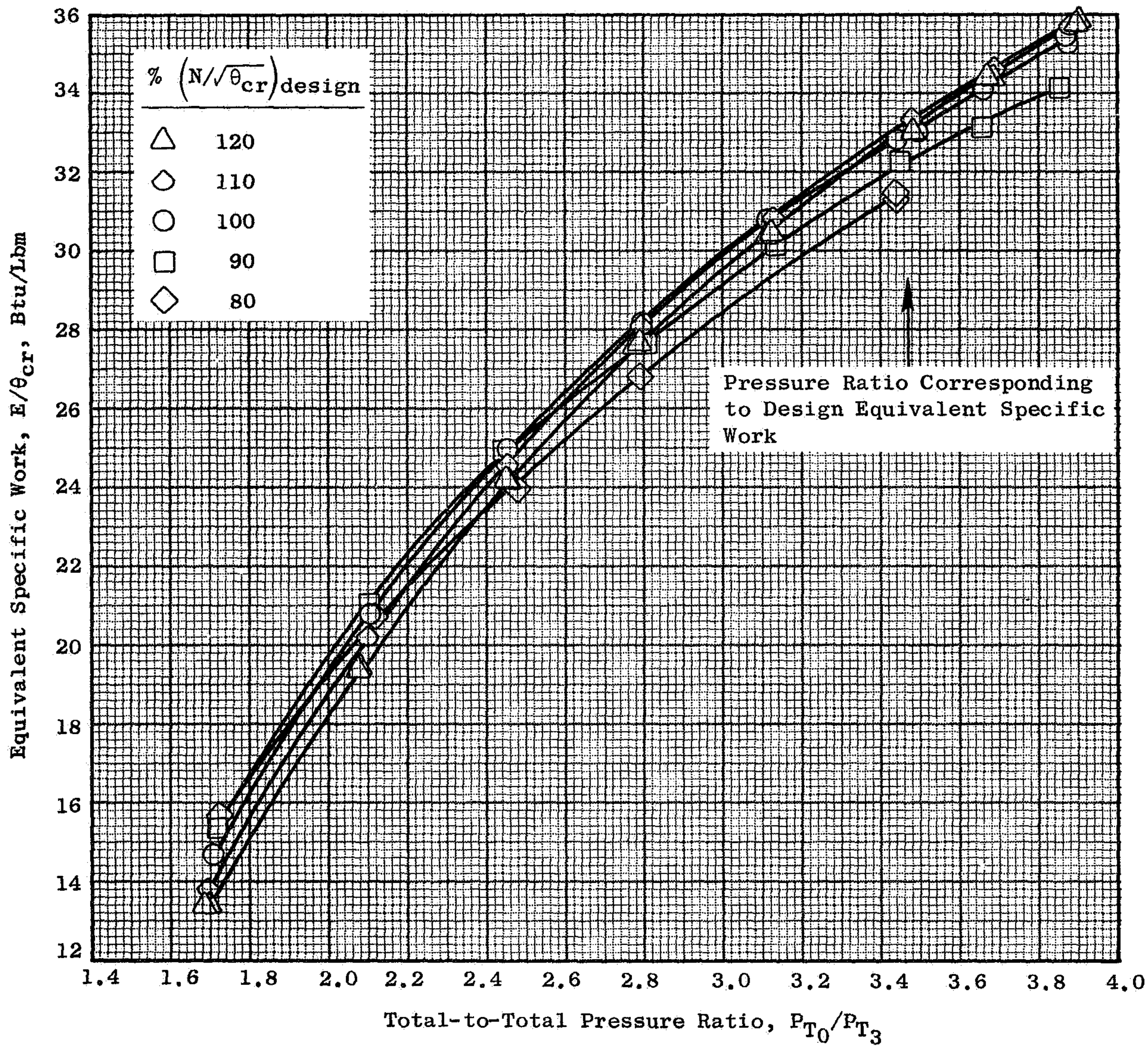


Figure 23. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

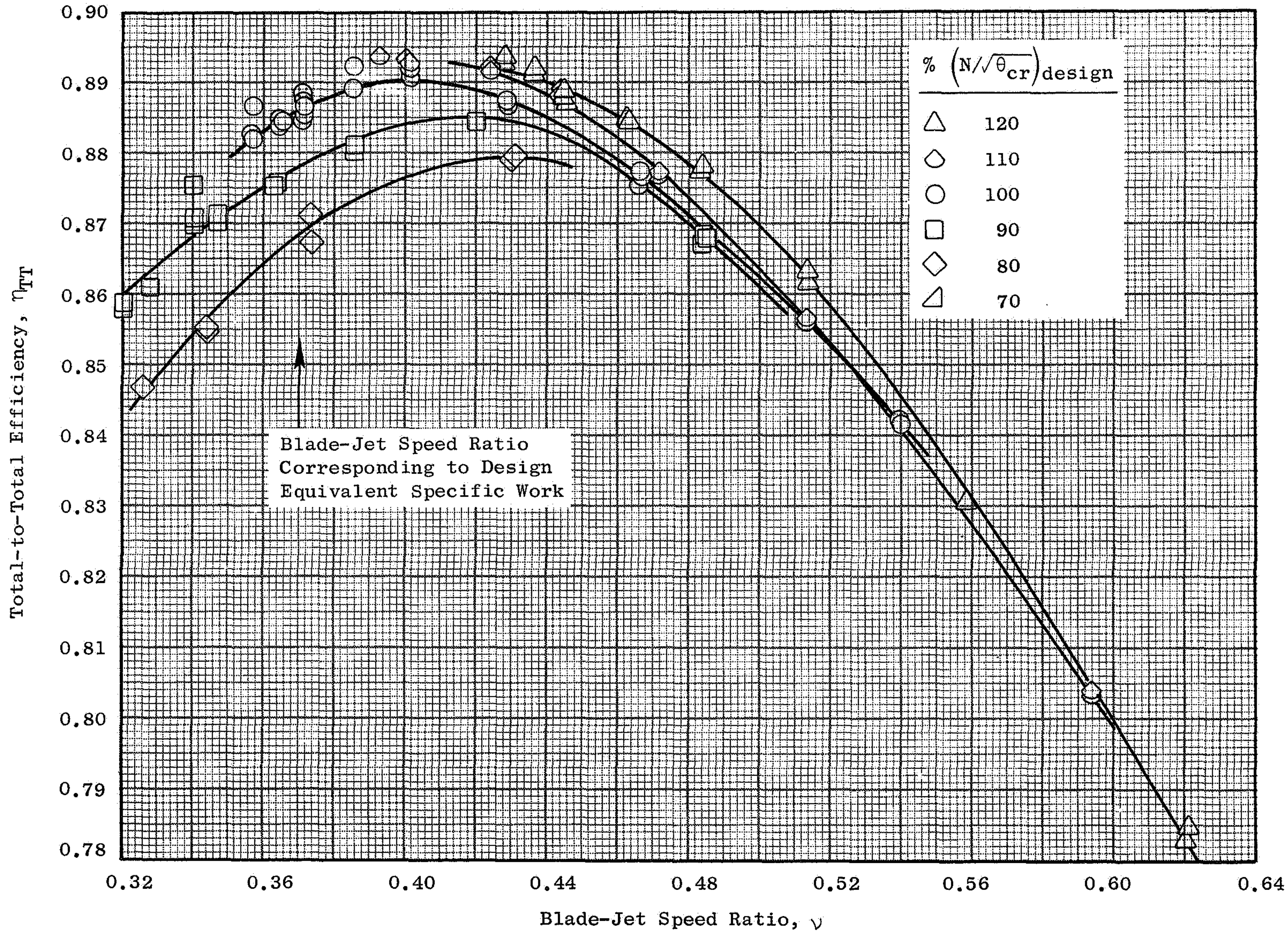


Figure 24. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 1 (PPPPPP).

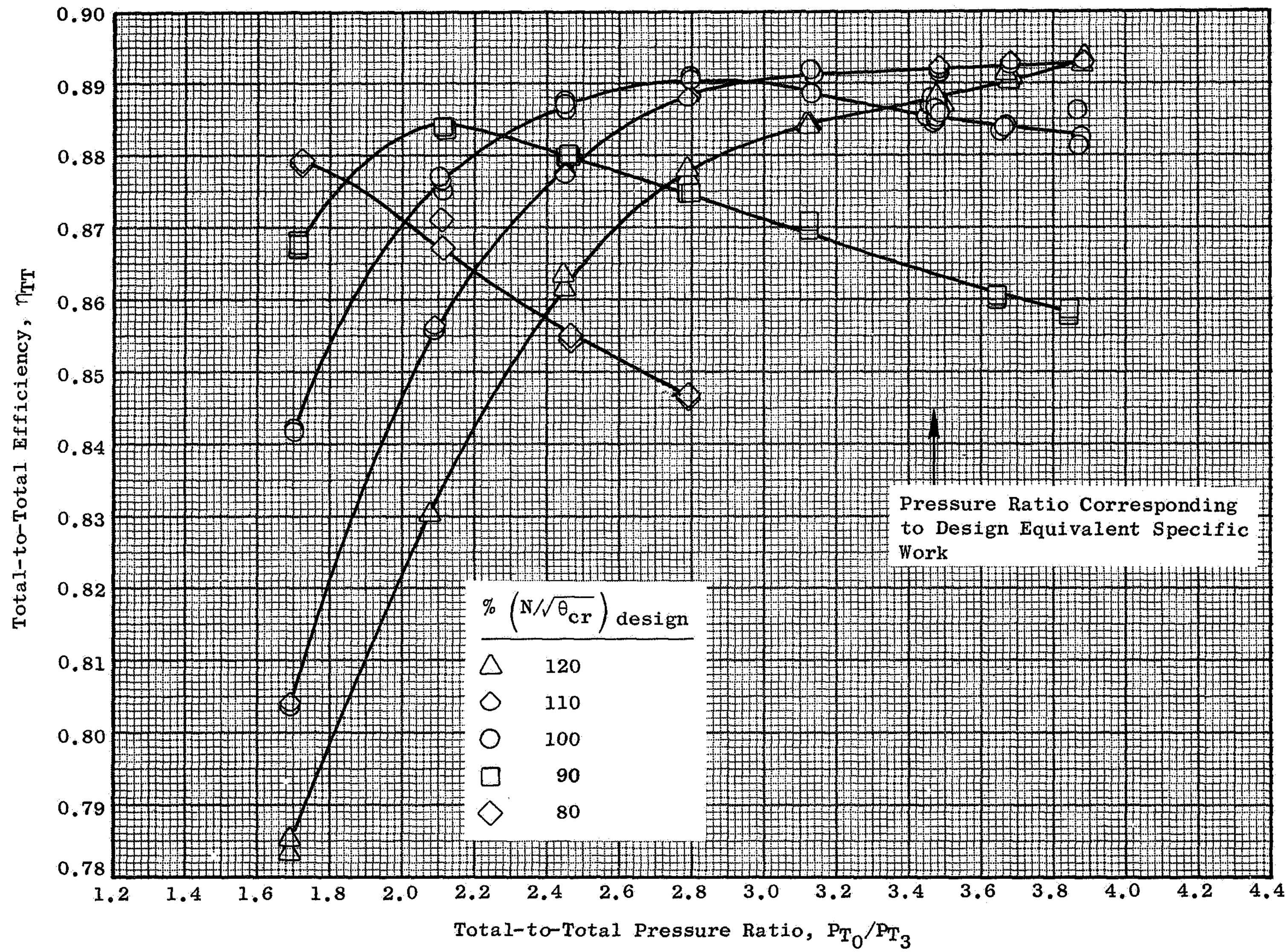


Figure 25. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

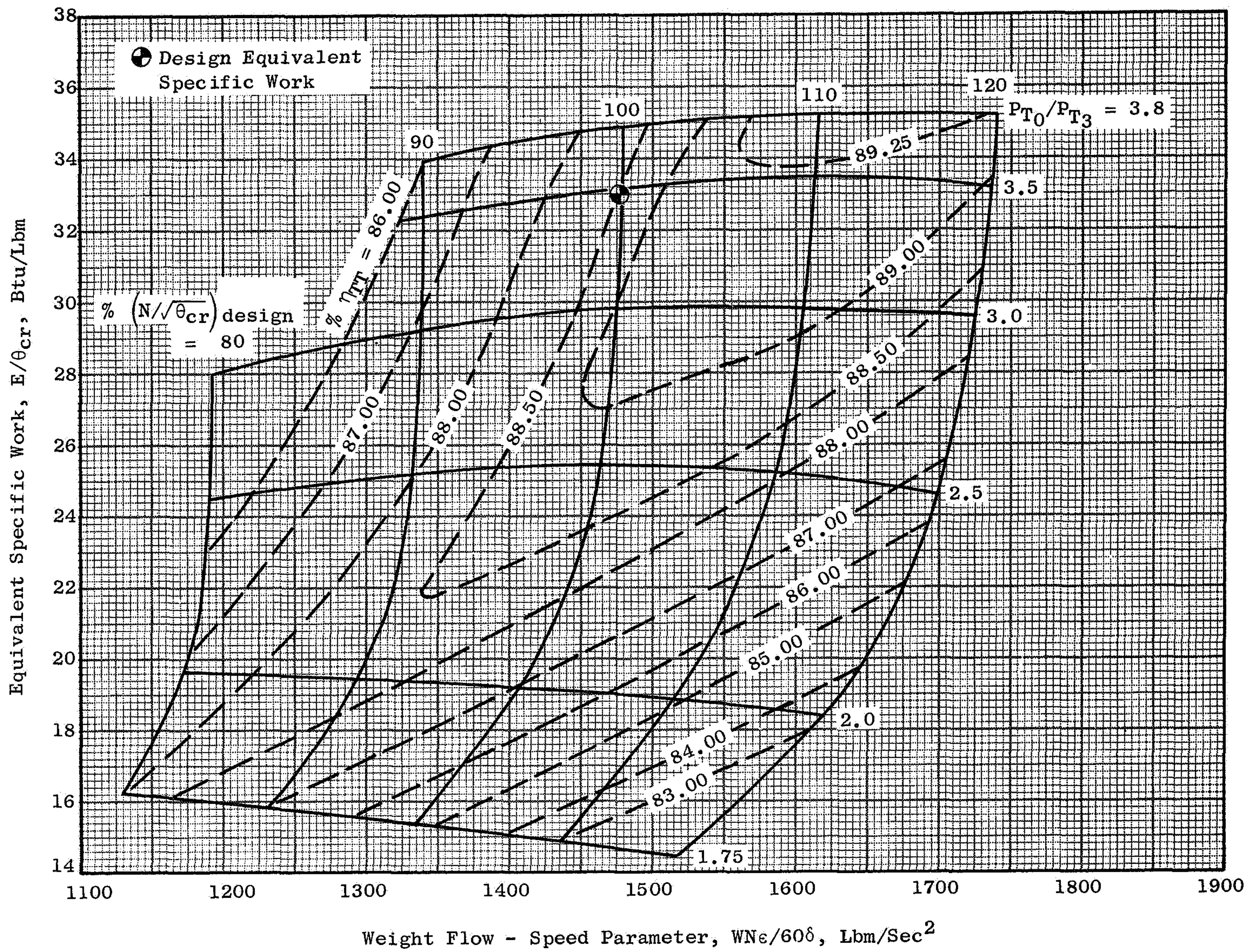


Figure 26. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 1 (PPPPPP).

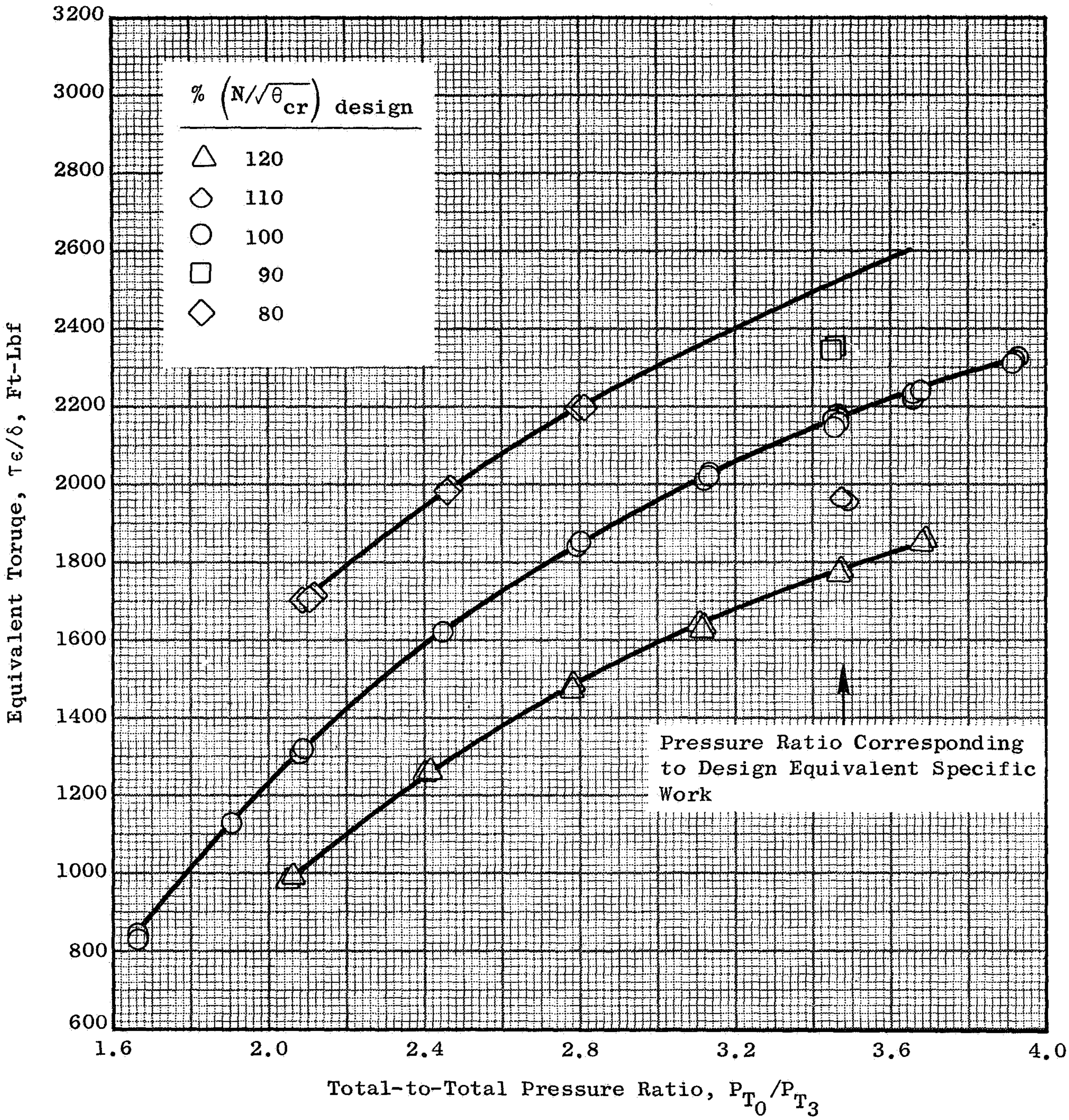


Figure 27. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 5 (PPPPPT).

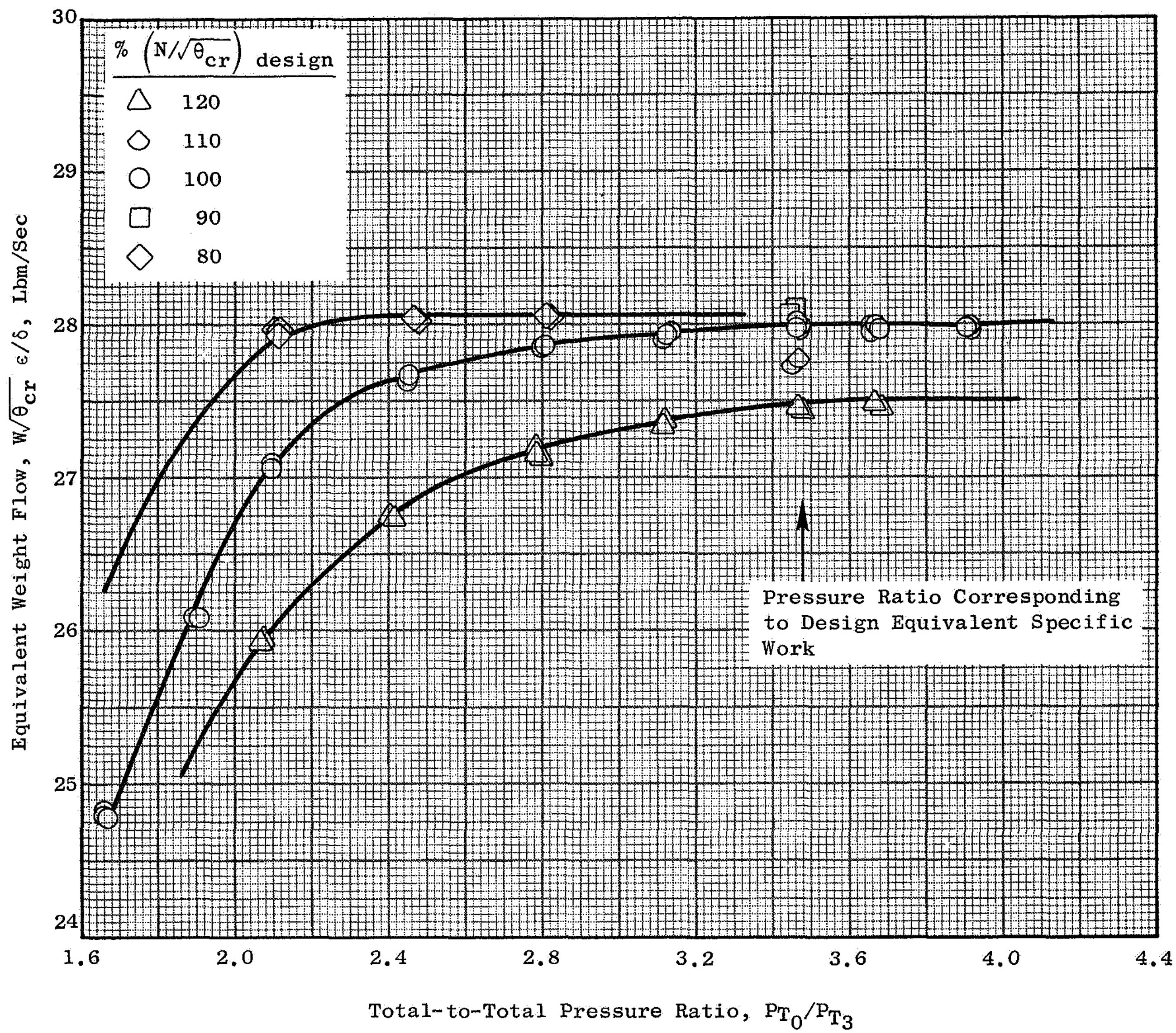


Figure 28. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 5 (PPPPPT).

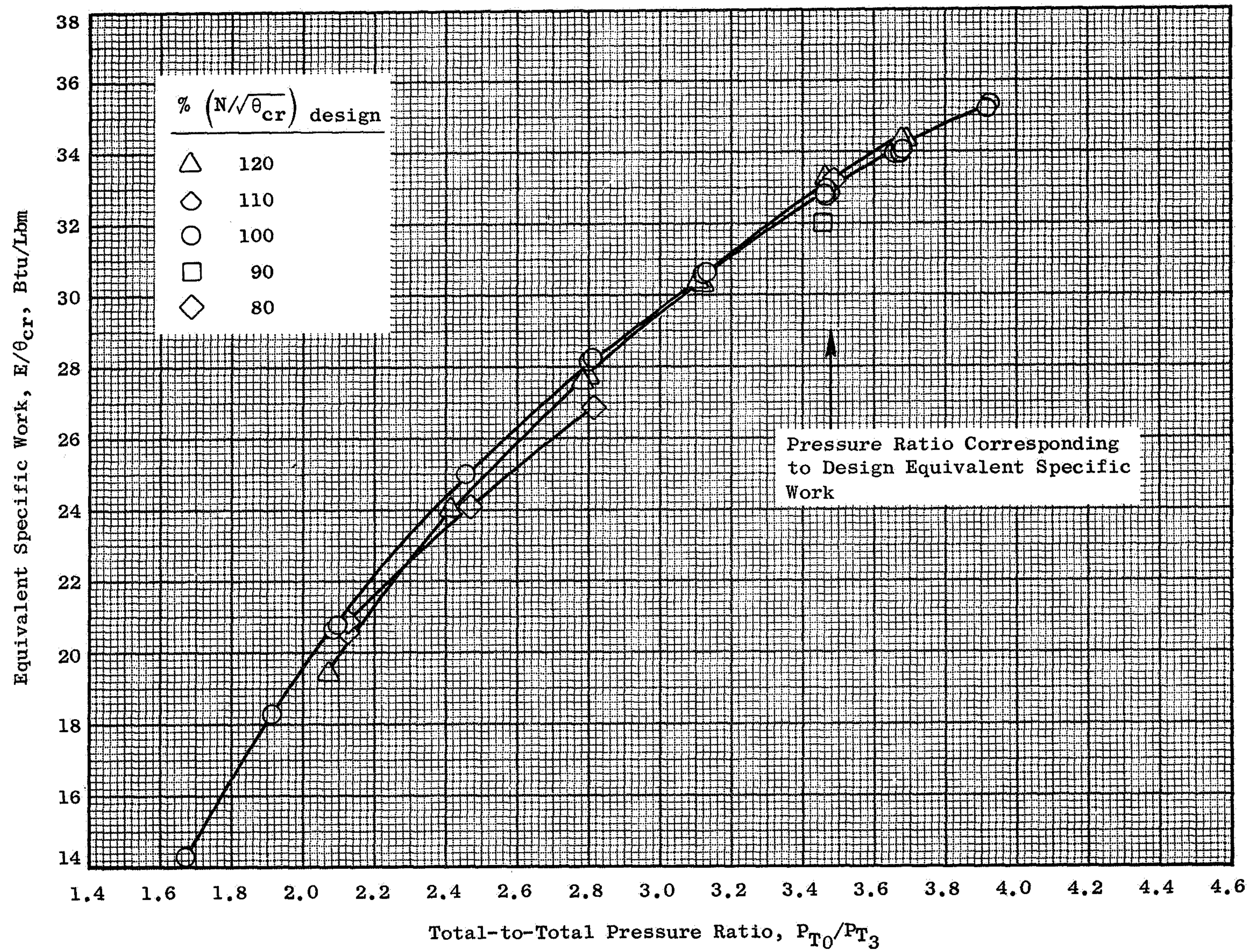


Figure 29. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 5 (PPPPPT).

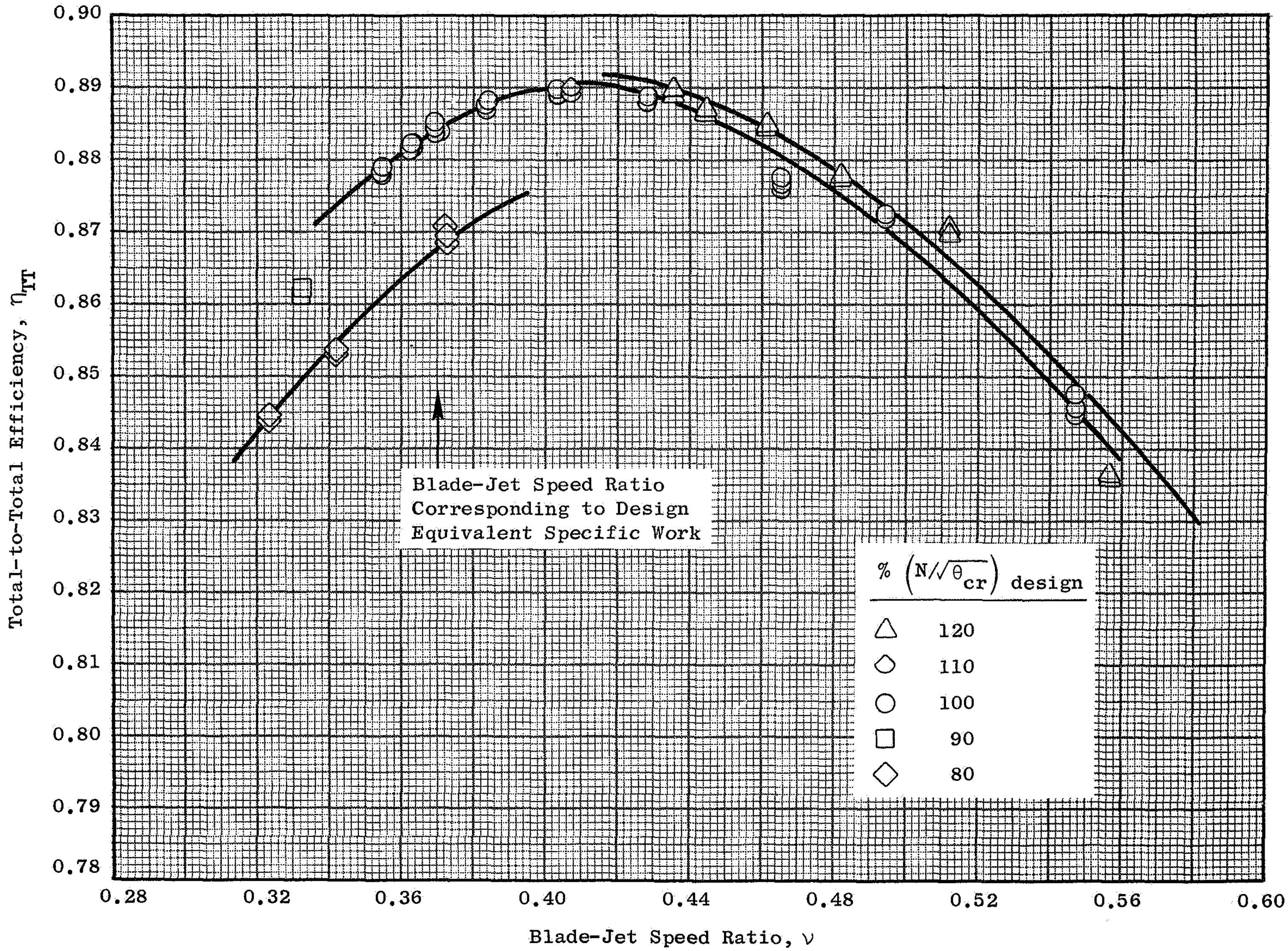


Figure 30. **Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 5 (PPPPPT).**

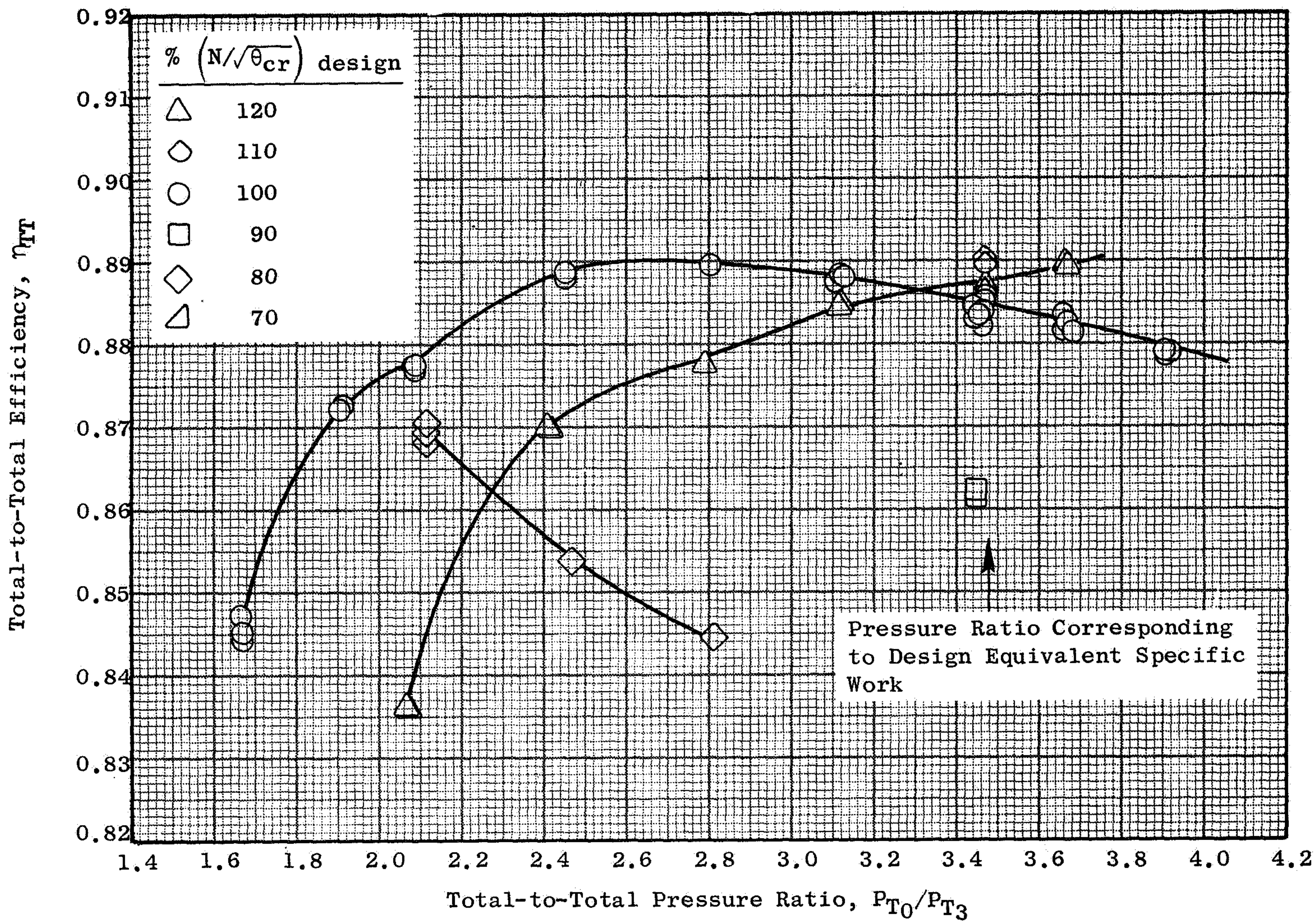


Figure 31. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 5 (PPPPPT).

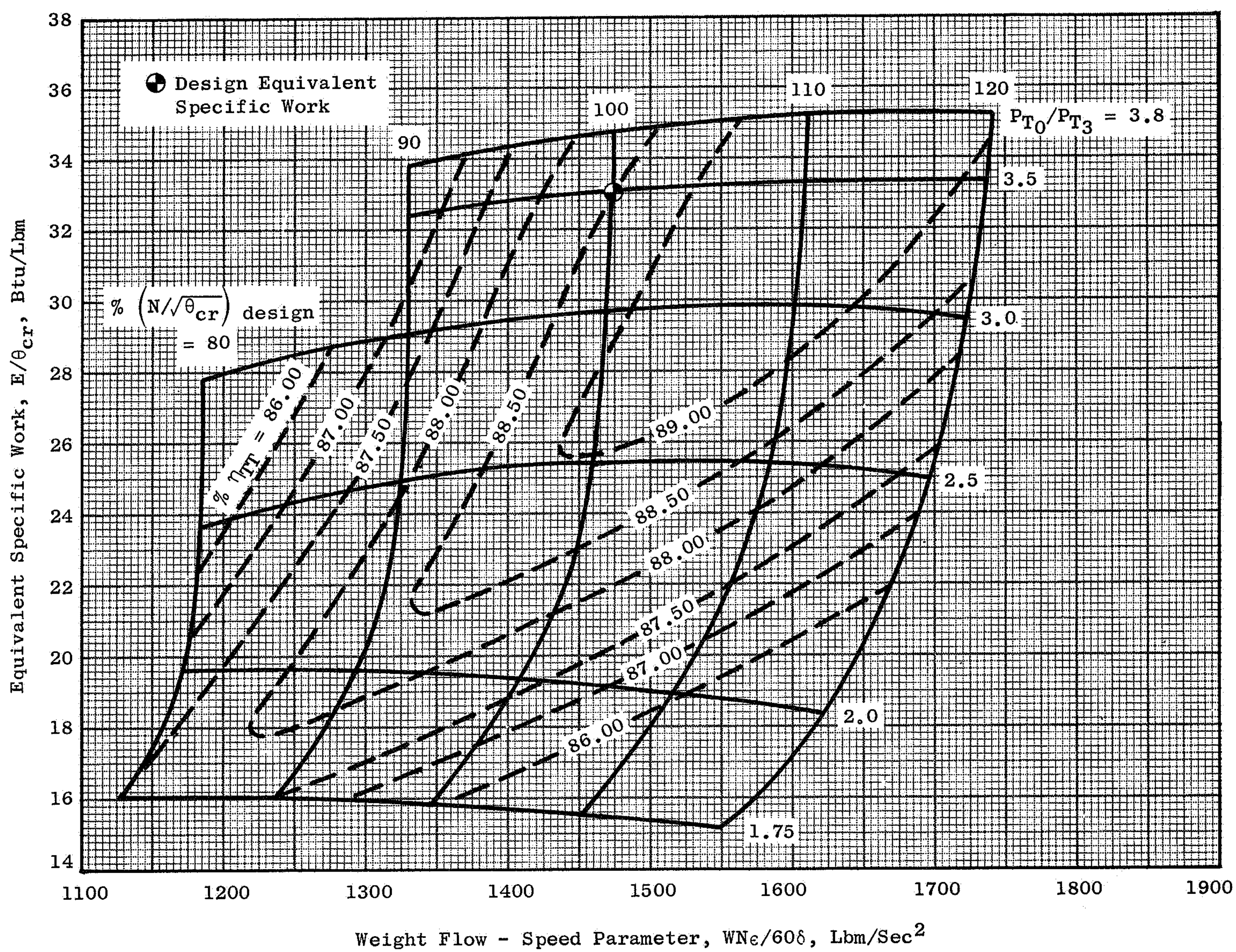


Figure 32. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 5 (PPPPPT).

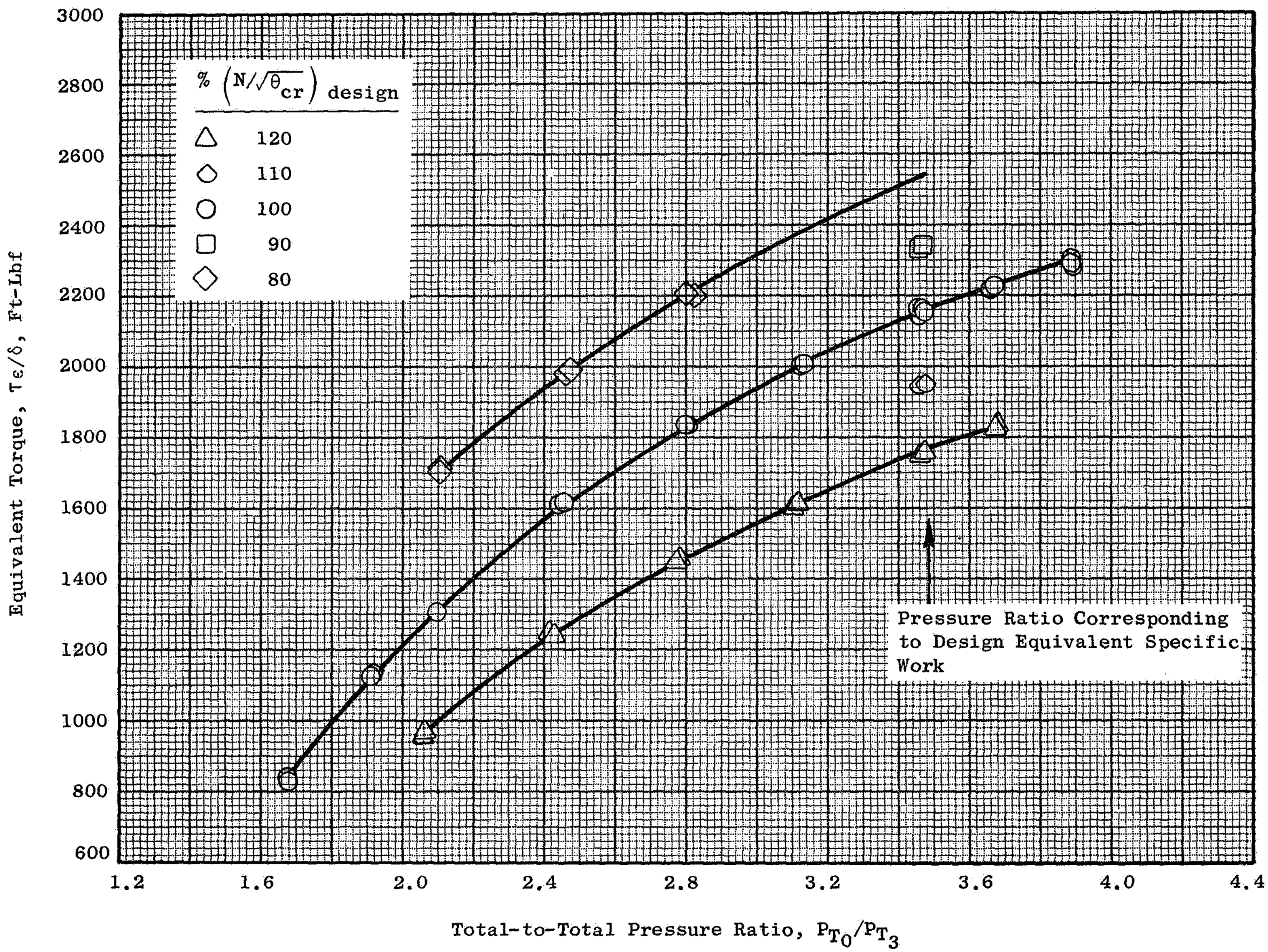


Figure 33. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 6 (PPTPTT).

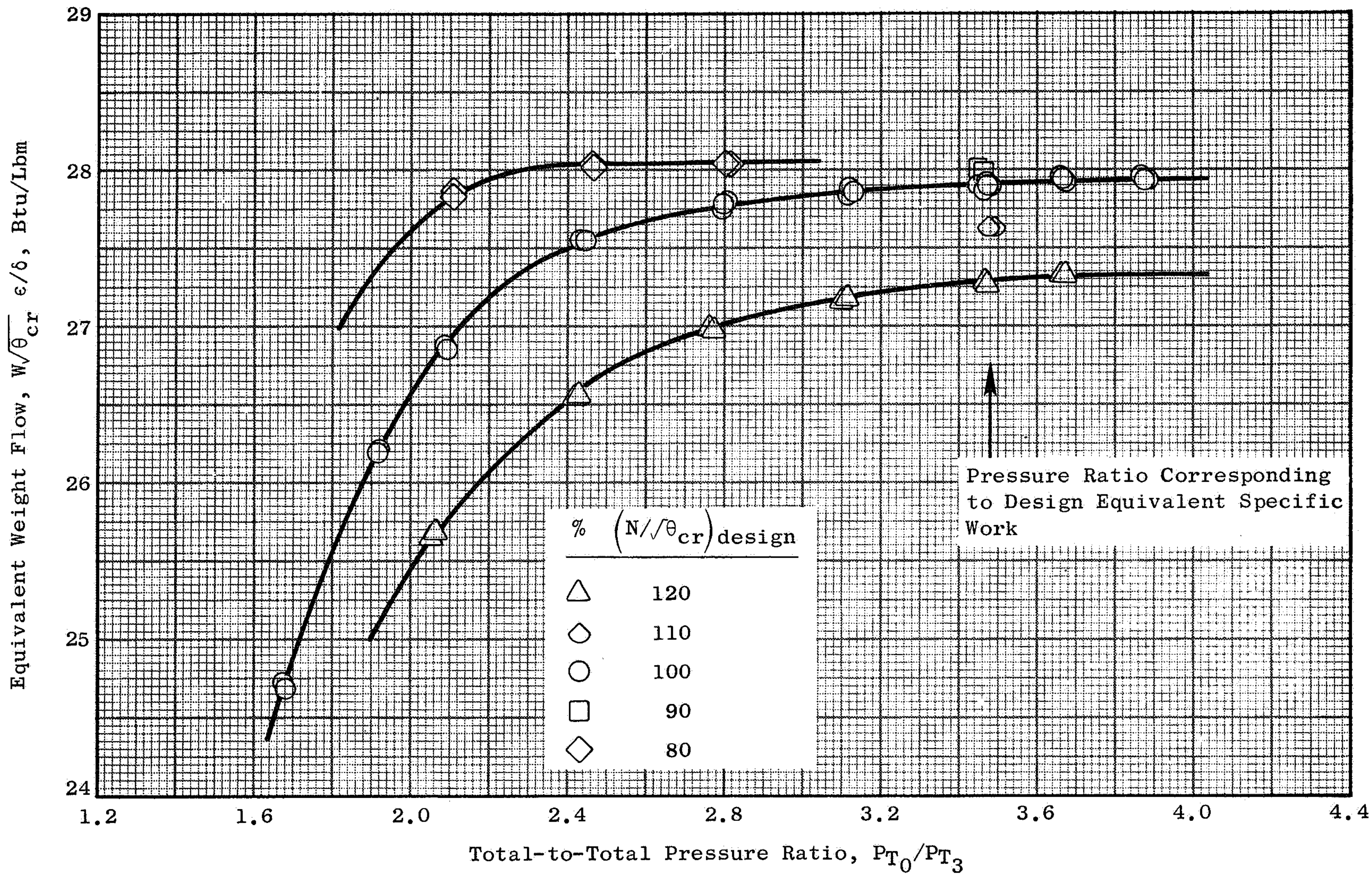


Figure 34. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 6 (PPTPTT).

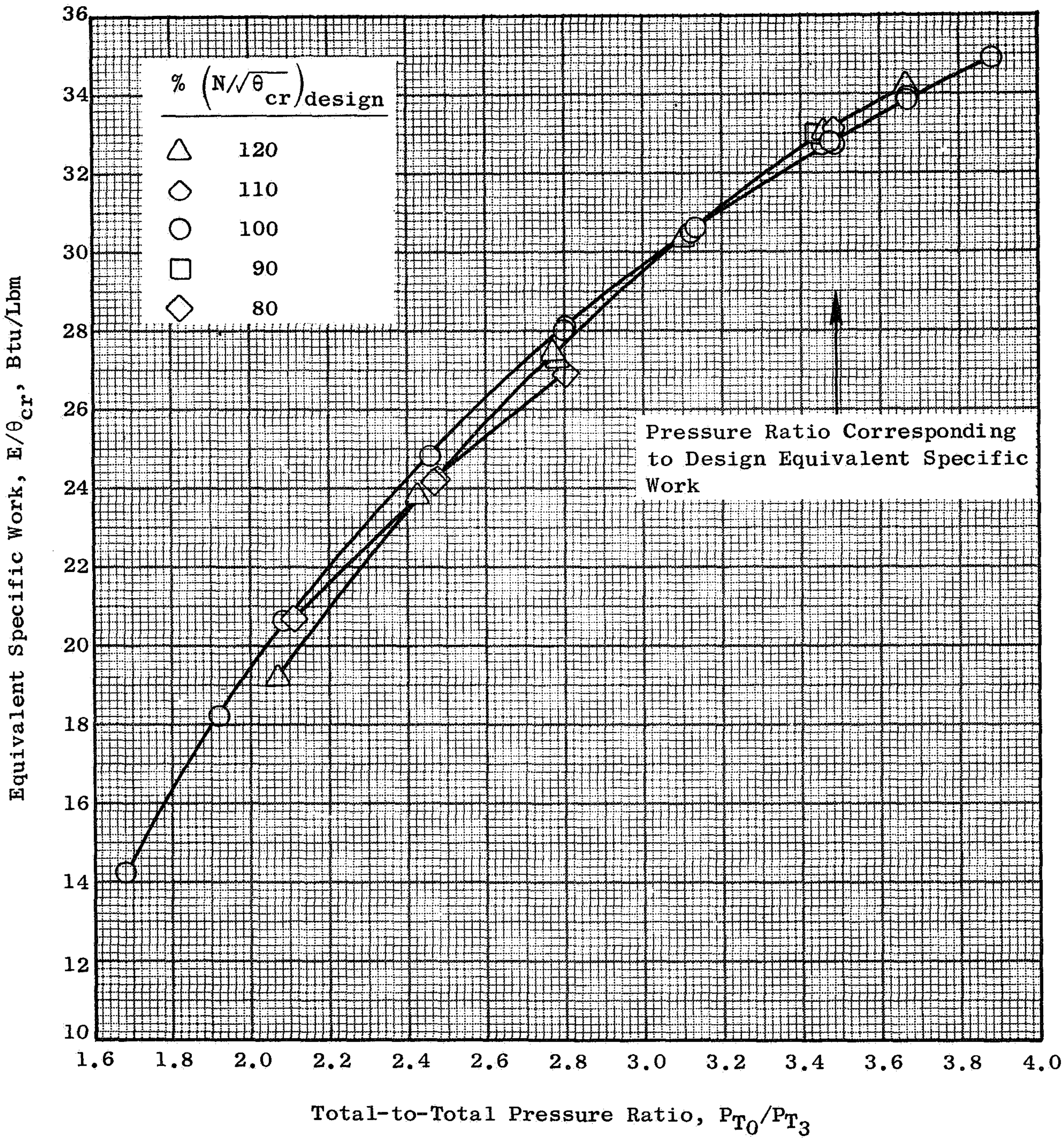


Figure 35. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 6 (PPTPTT).

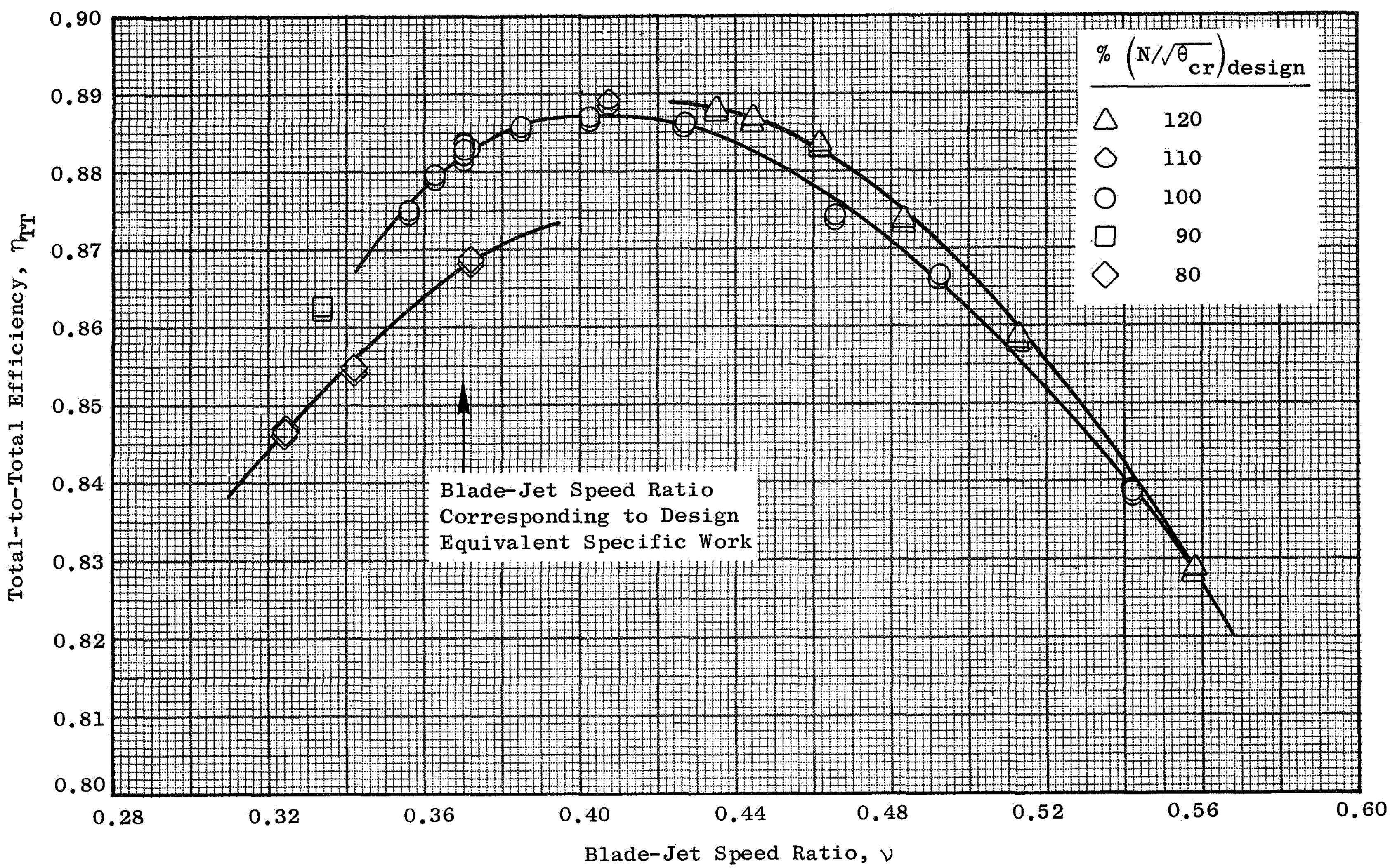


Figure 36. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 6 (PPTPTT).

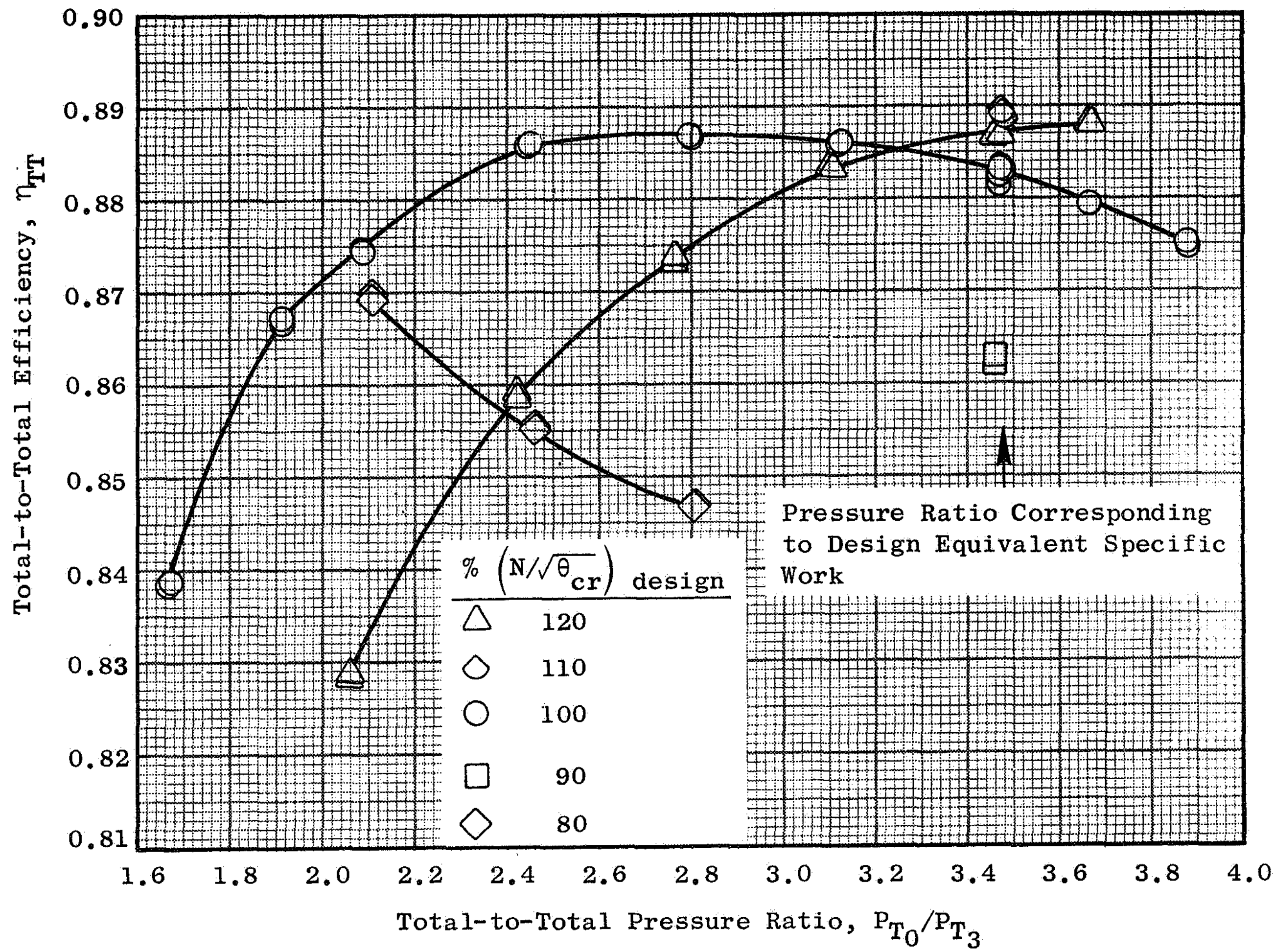


Figure 37. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 6 (PPTPTT).

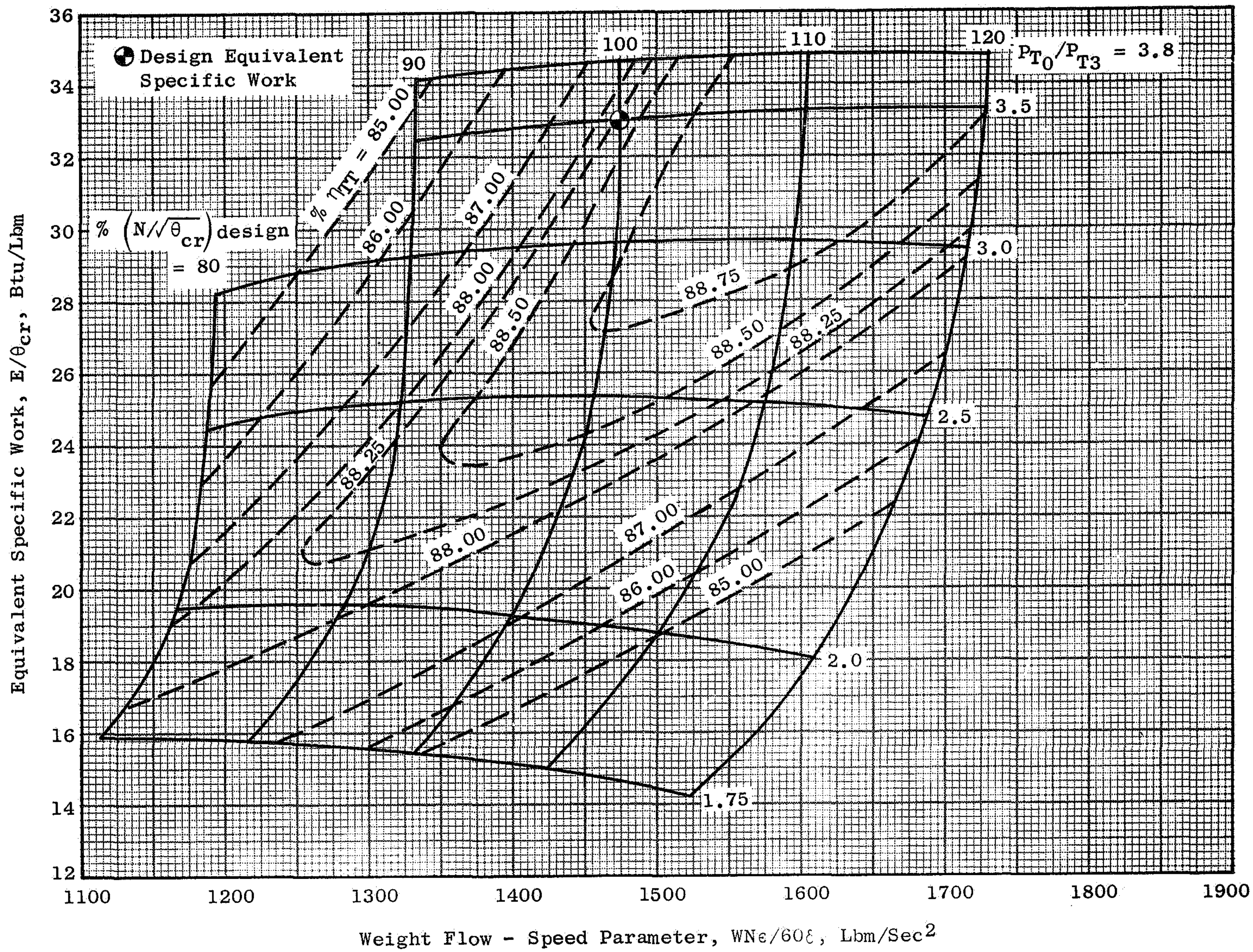


Figure 38. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 6 (PPTPTT).

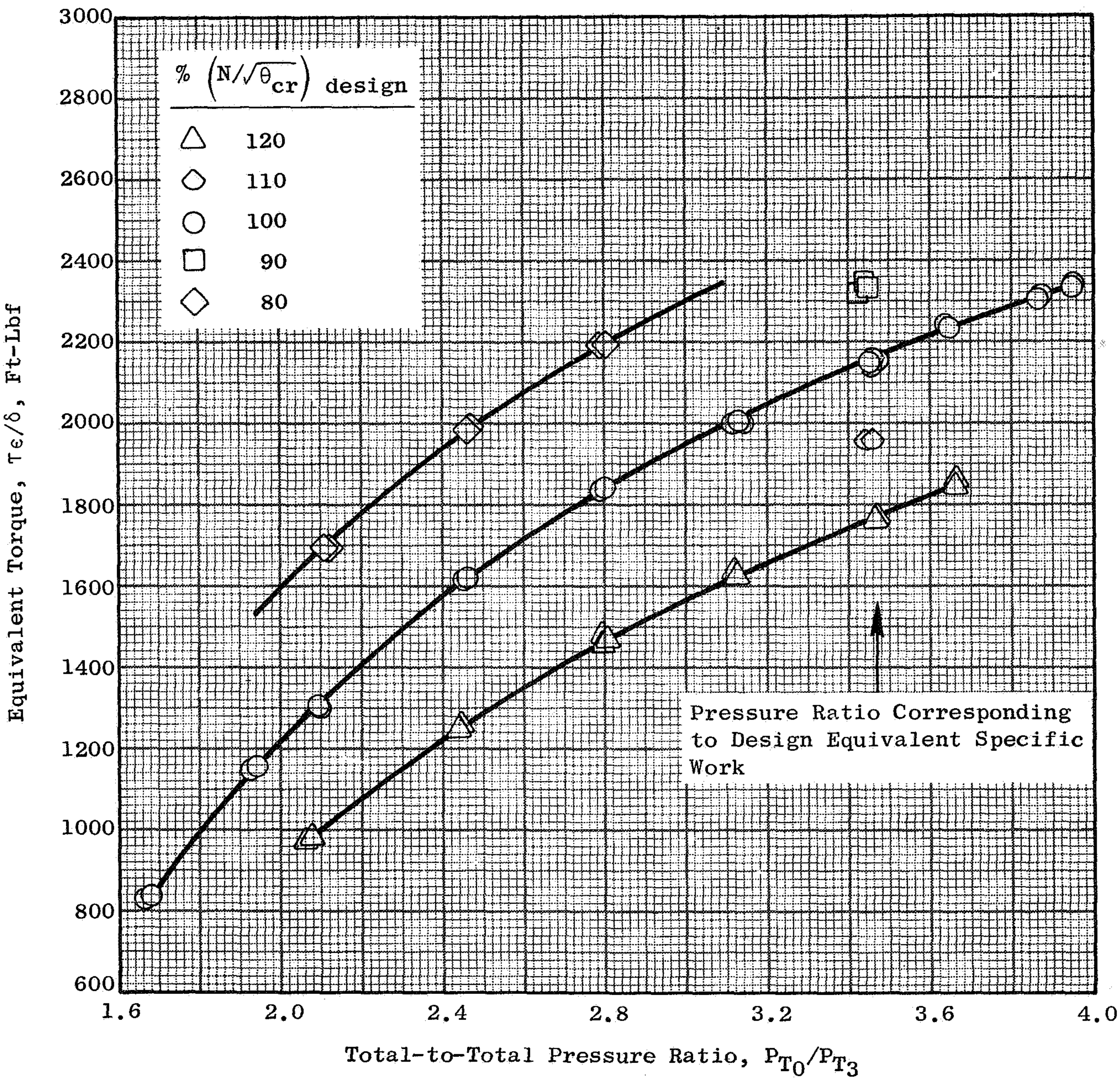


Figure 39. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 7 (PPPPLP).

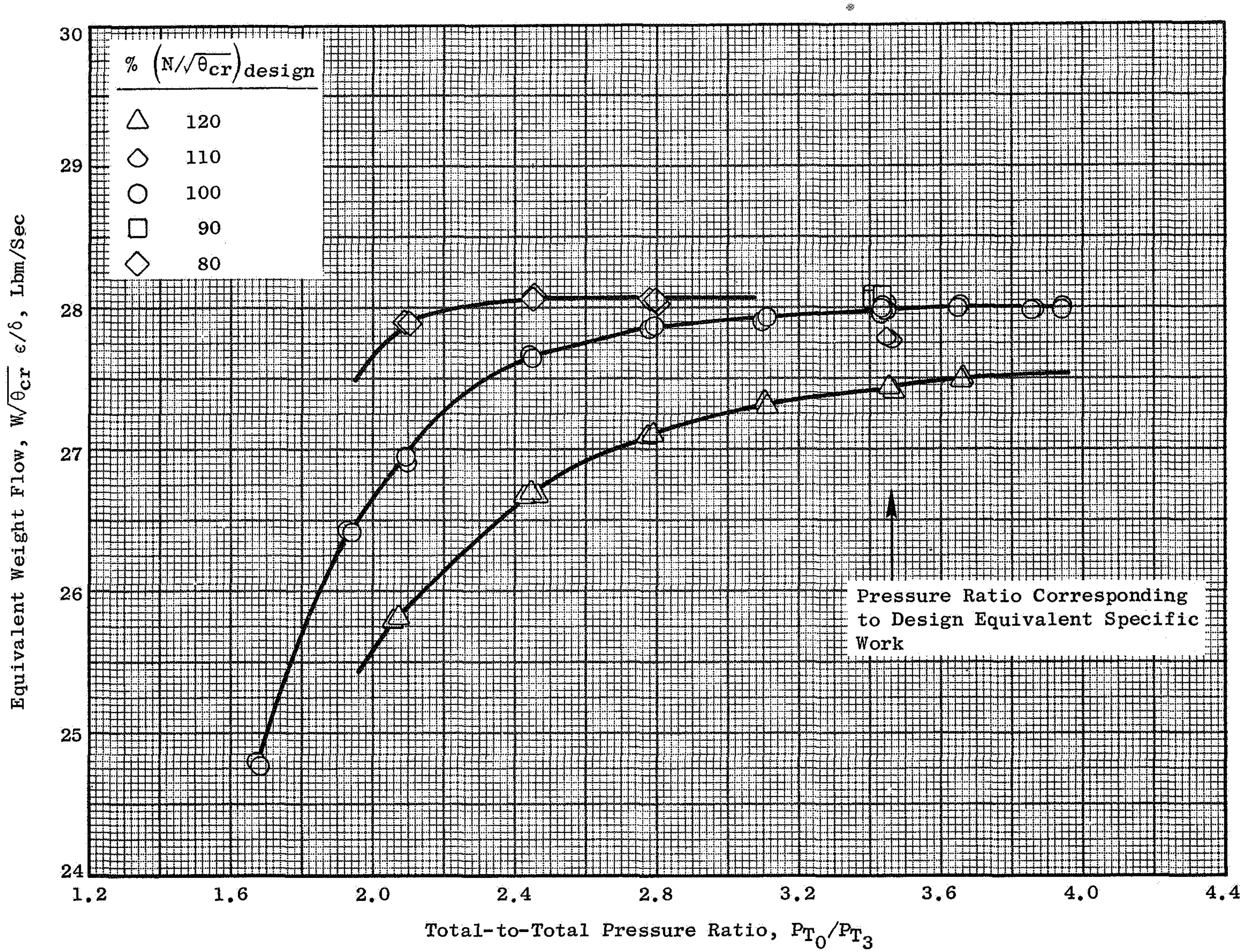


Figure 40. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 7 (PPPPLP).

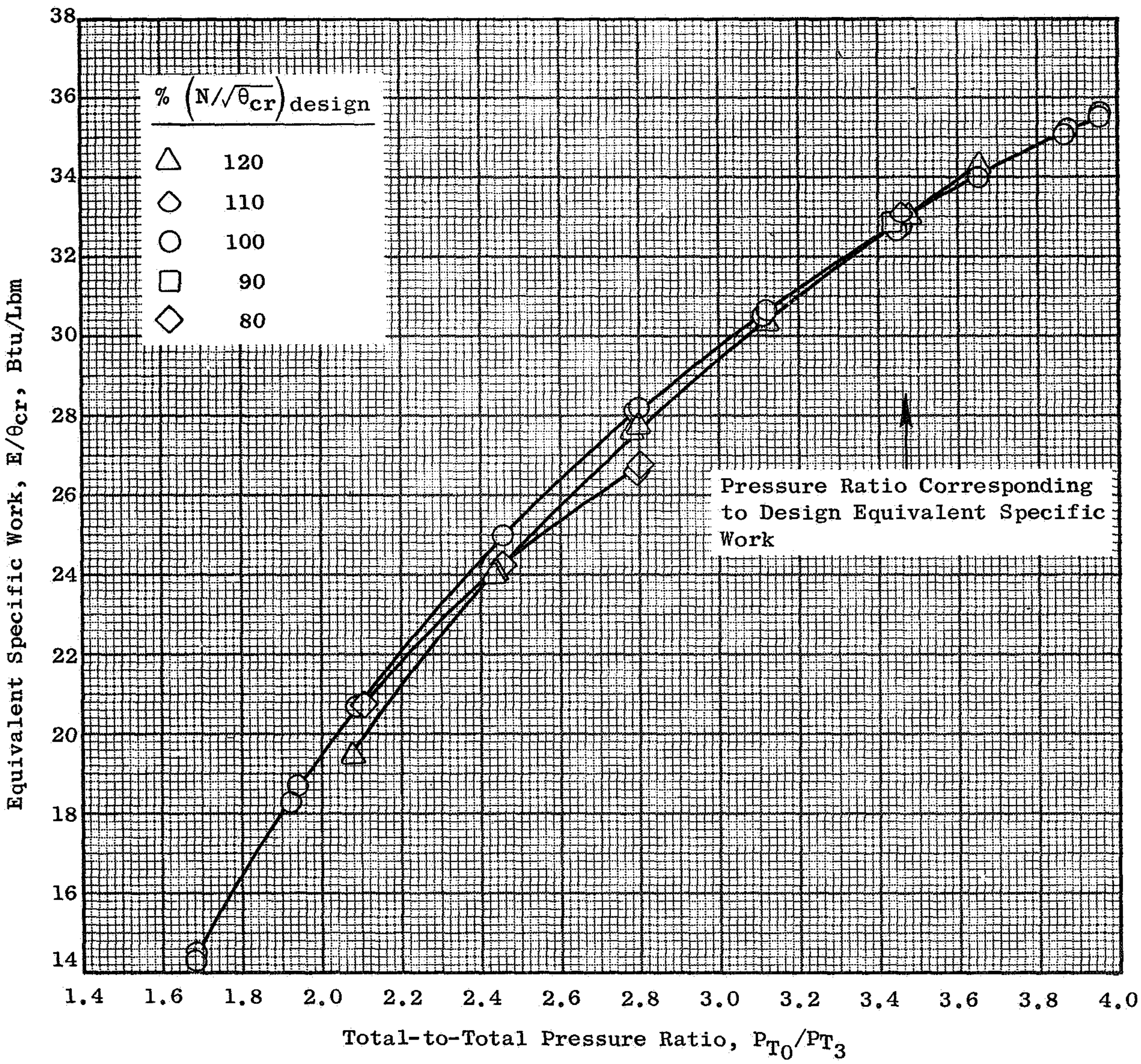


Figure 41. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 7 (PPPPLP).

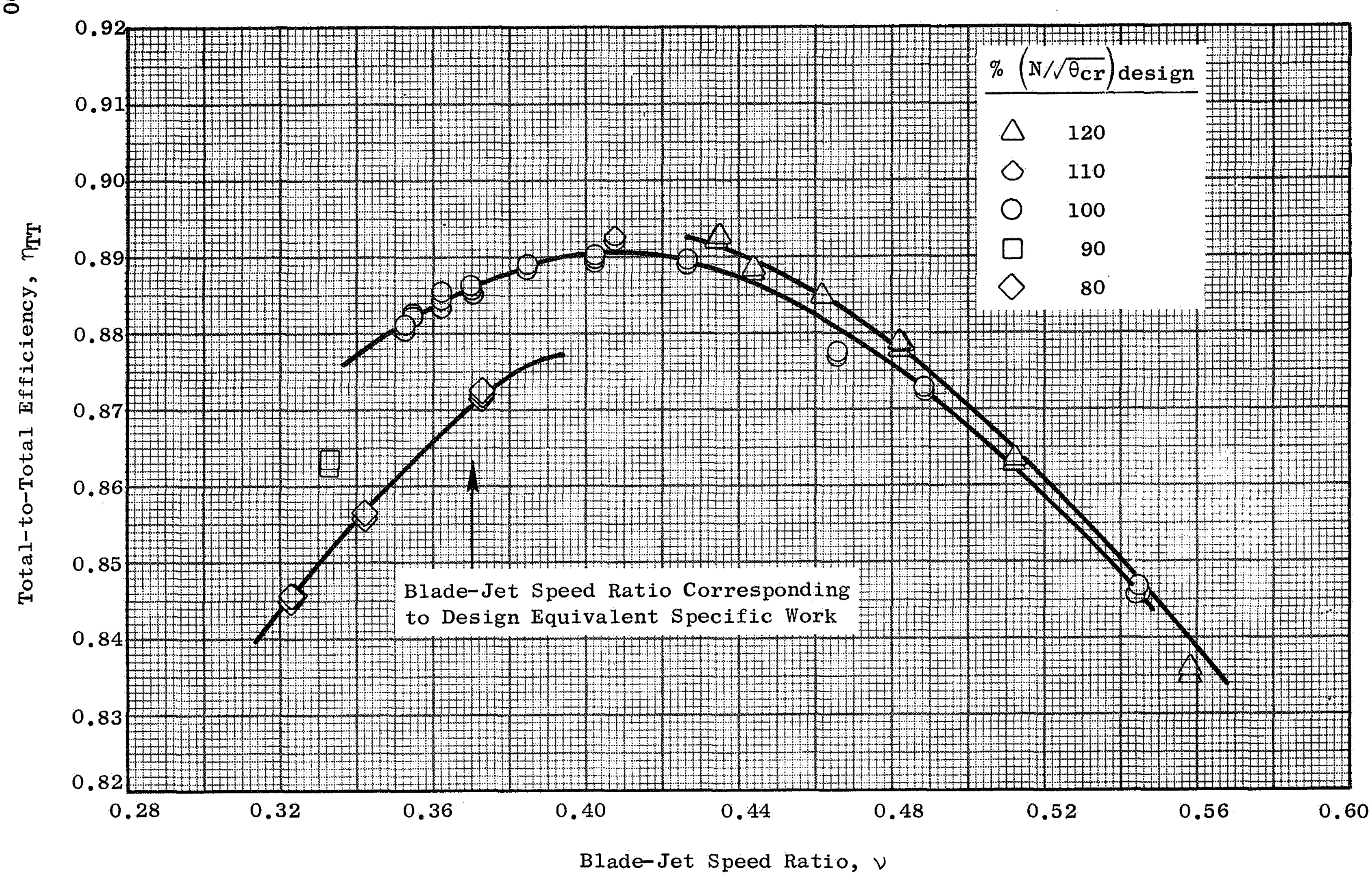


Figure 42. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 7 (PPPPLP).

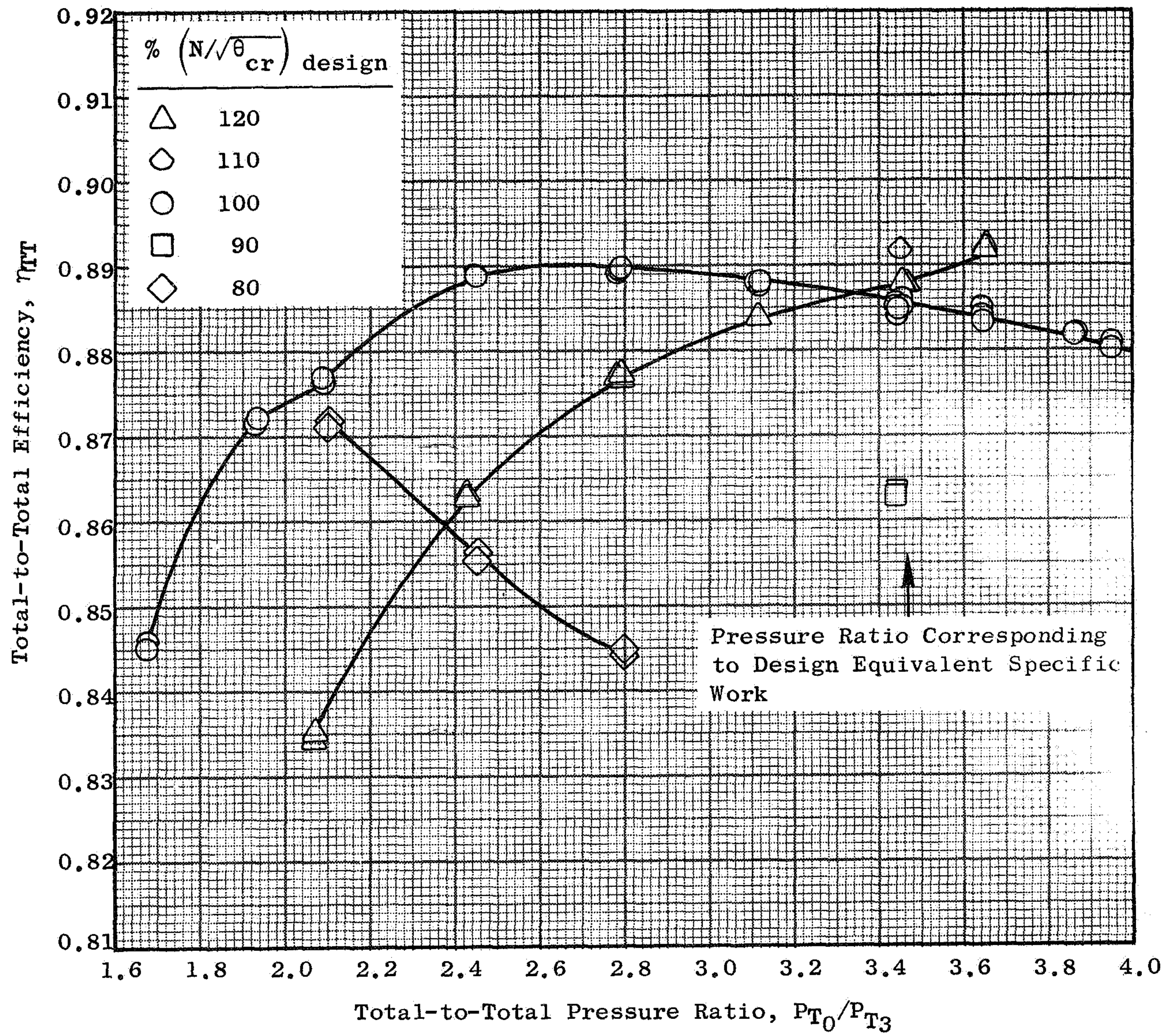


Figure 43. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 7 (PPPPLP).

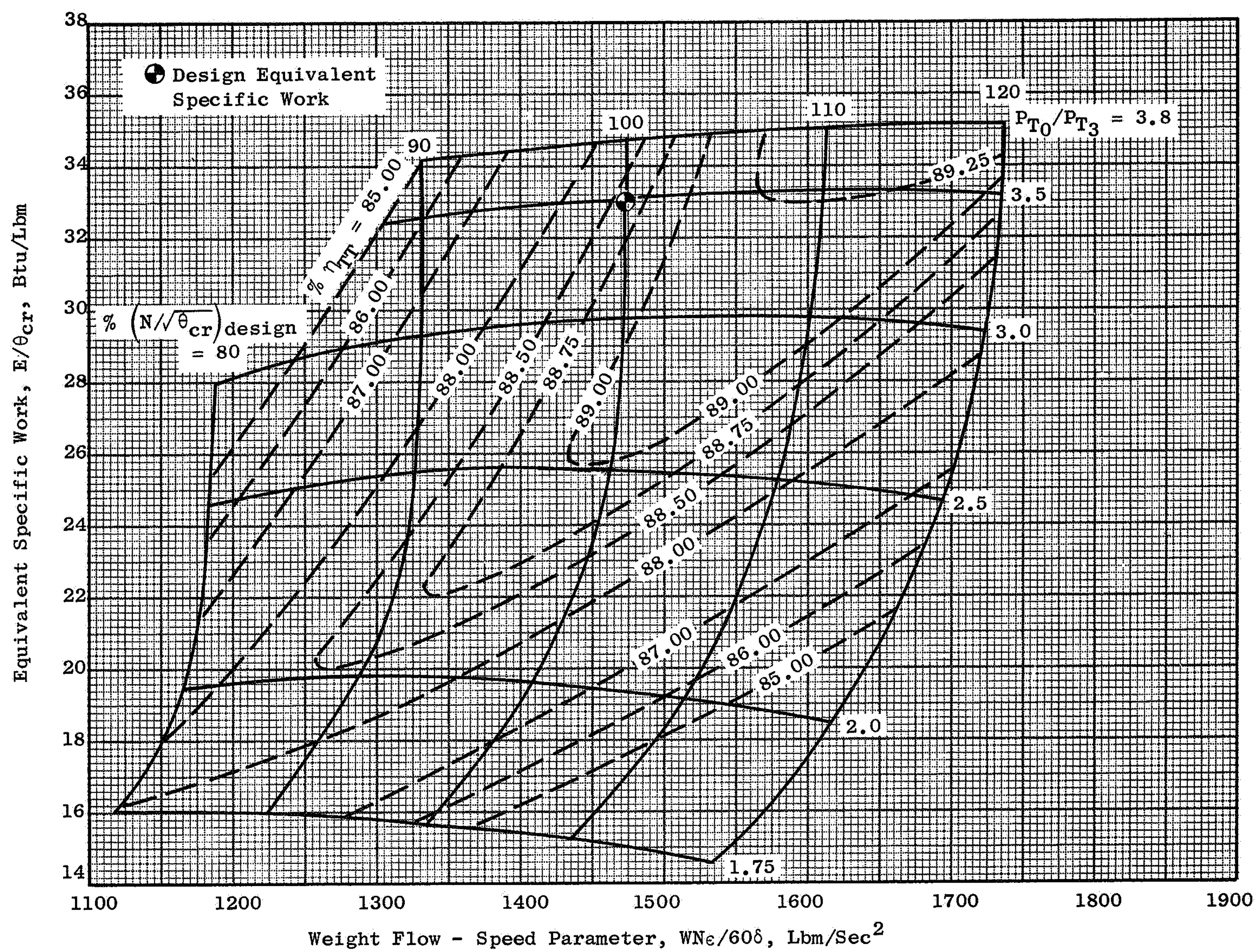


Figure 44. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 7 (PPPPLP).

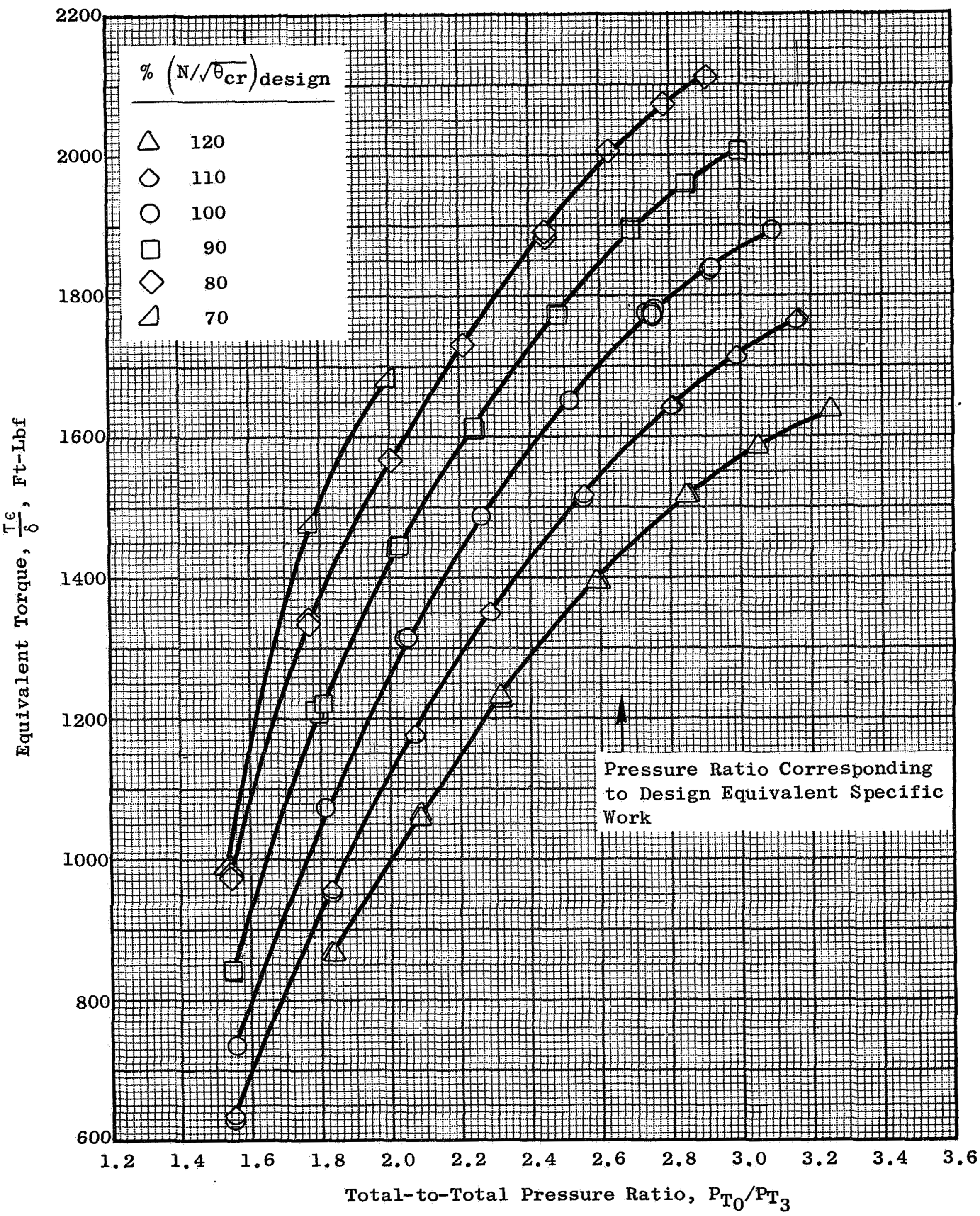


Figure 45. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

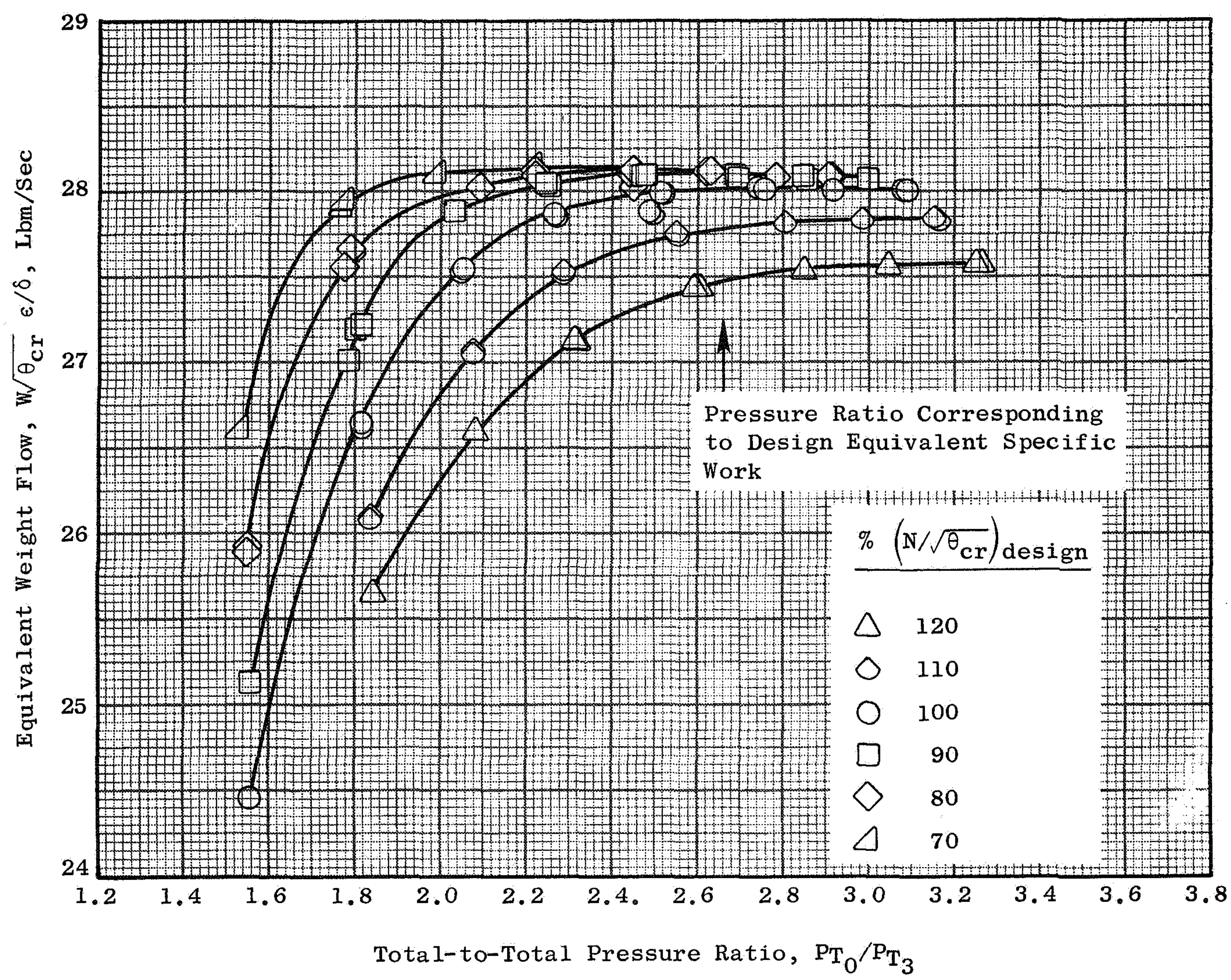


Figure 46. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

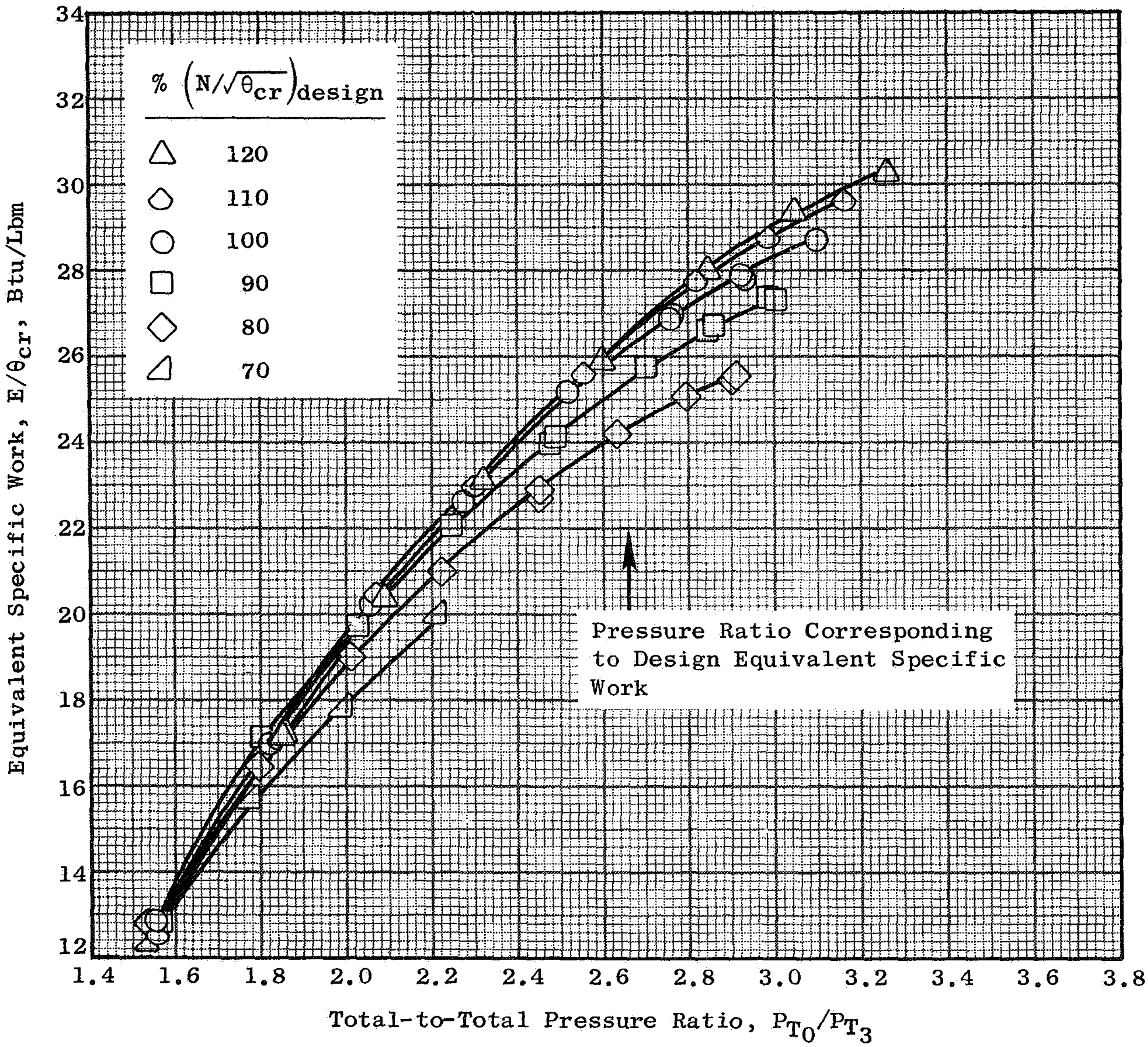


Figure 47. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

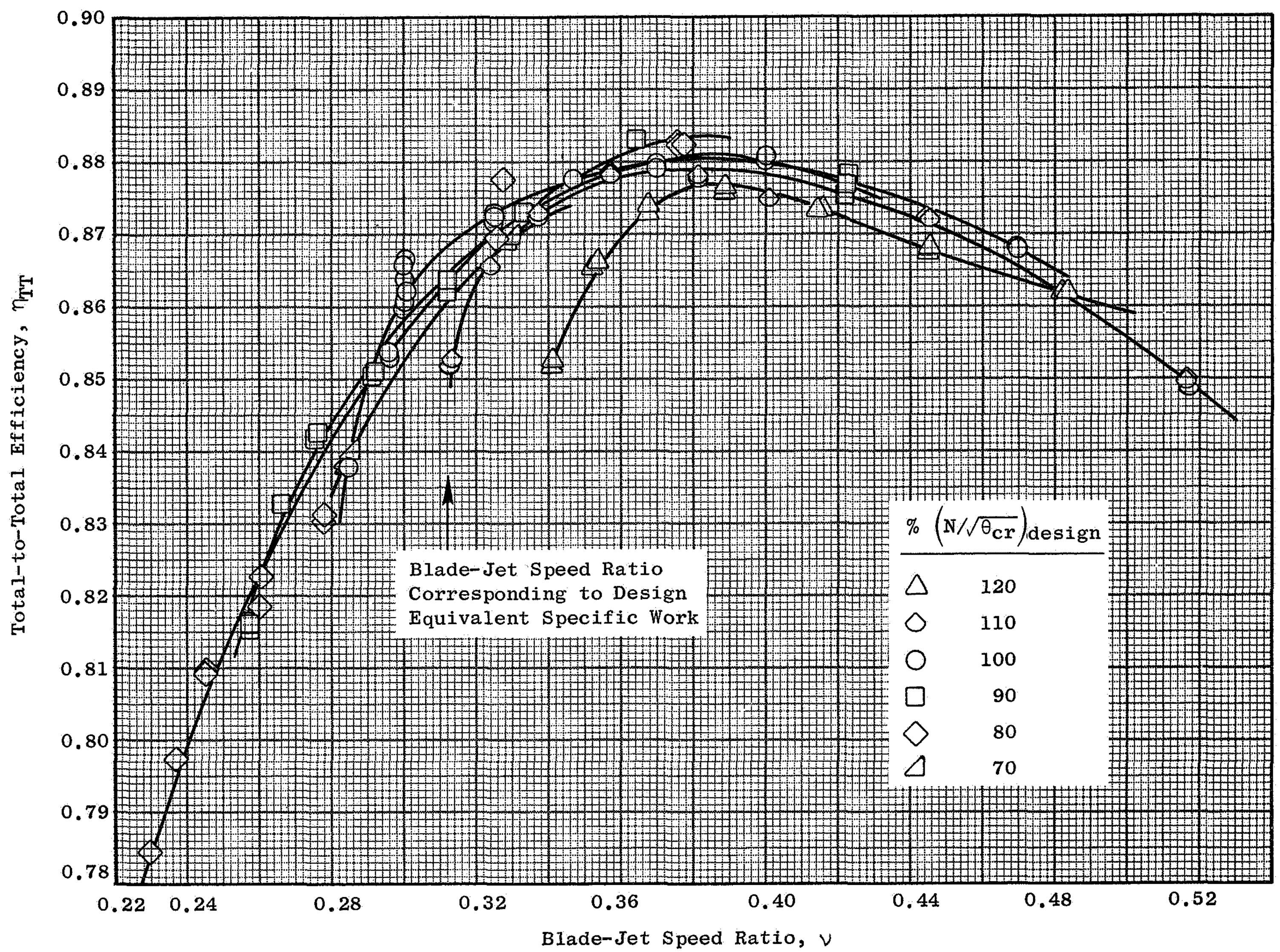


Figure 48. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 2 (PPPP).

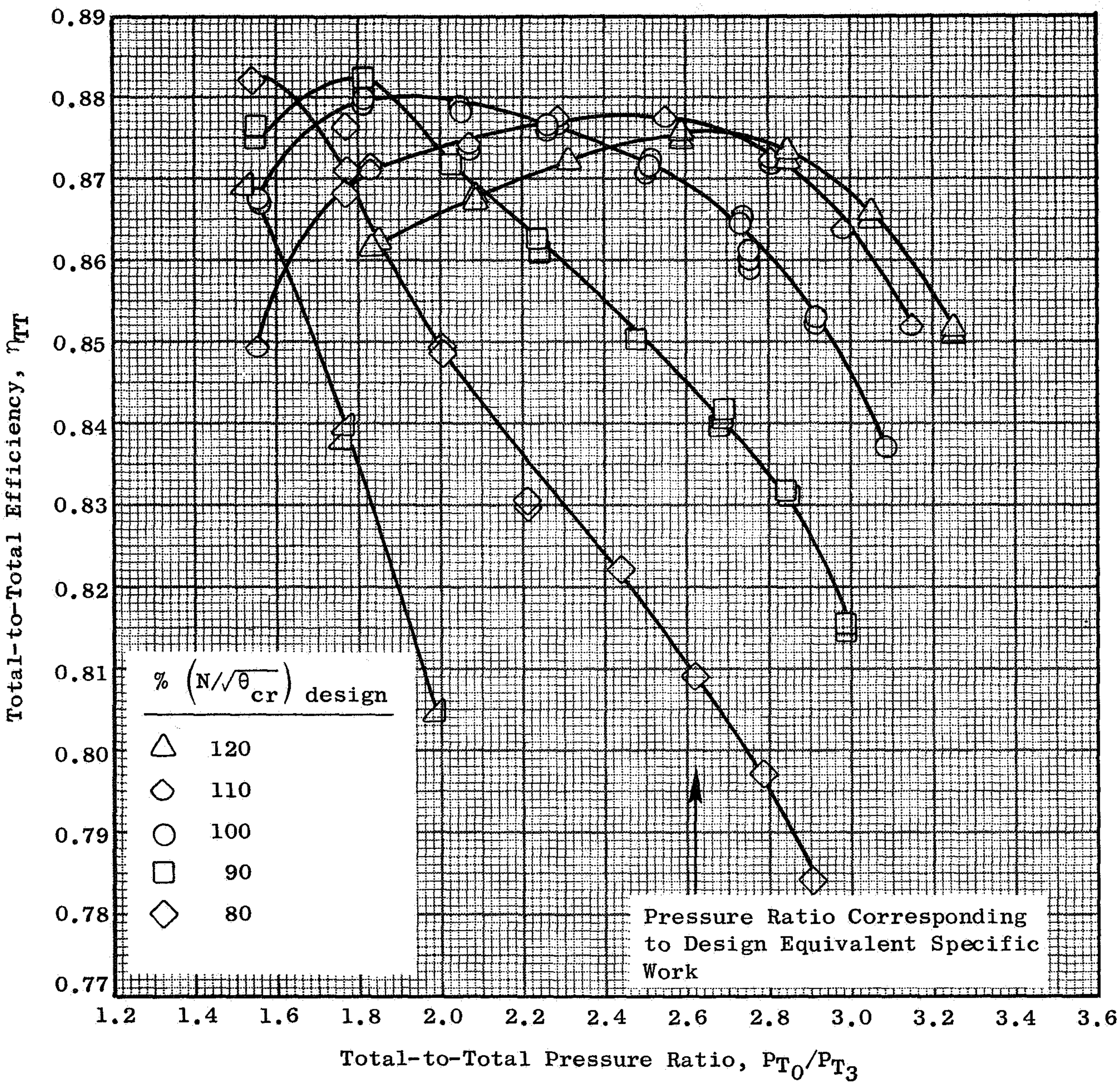


Figure 49. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

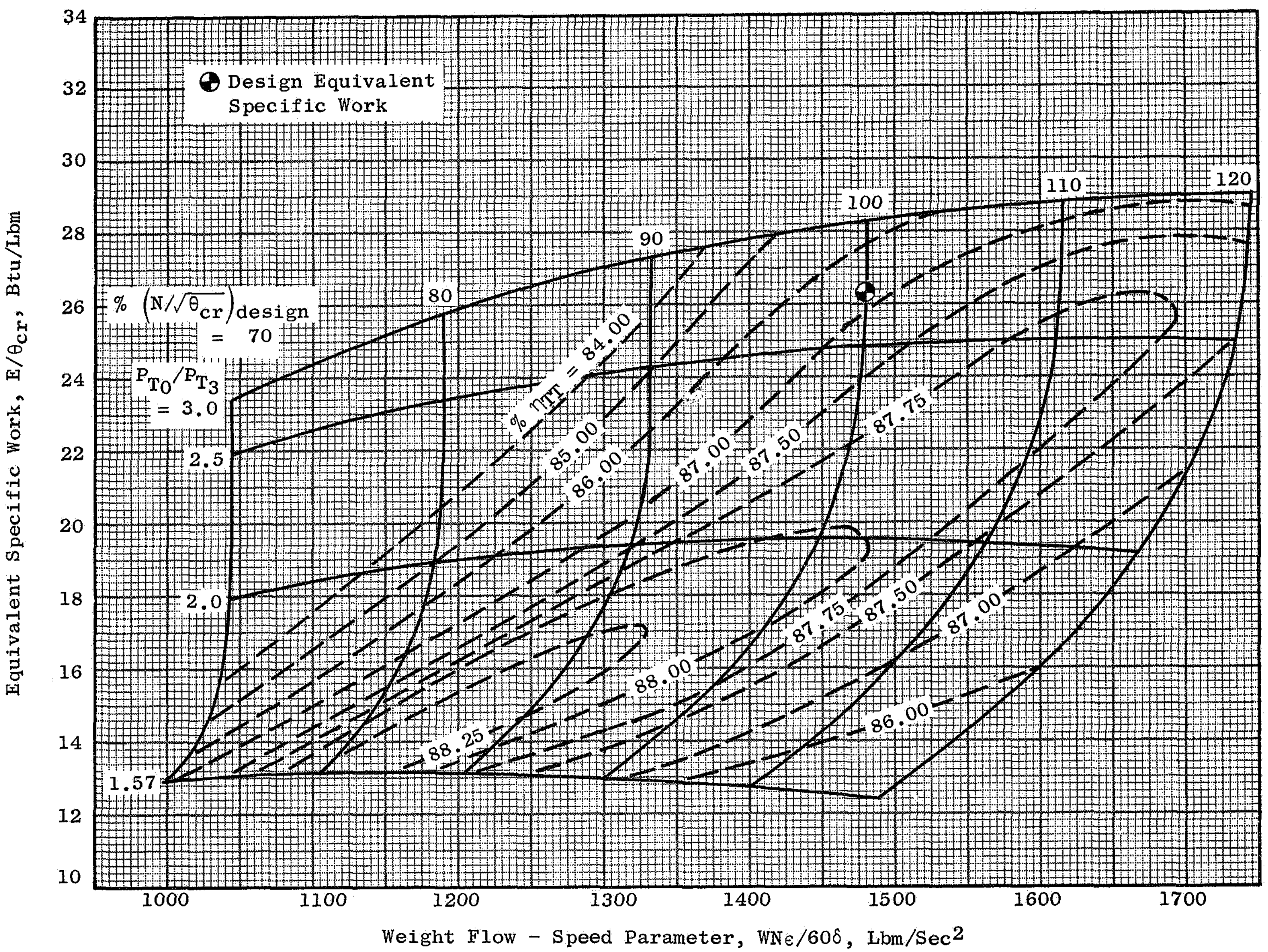


Figure 50. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 2 (PPPP).

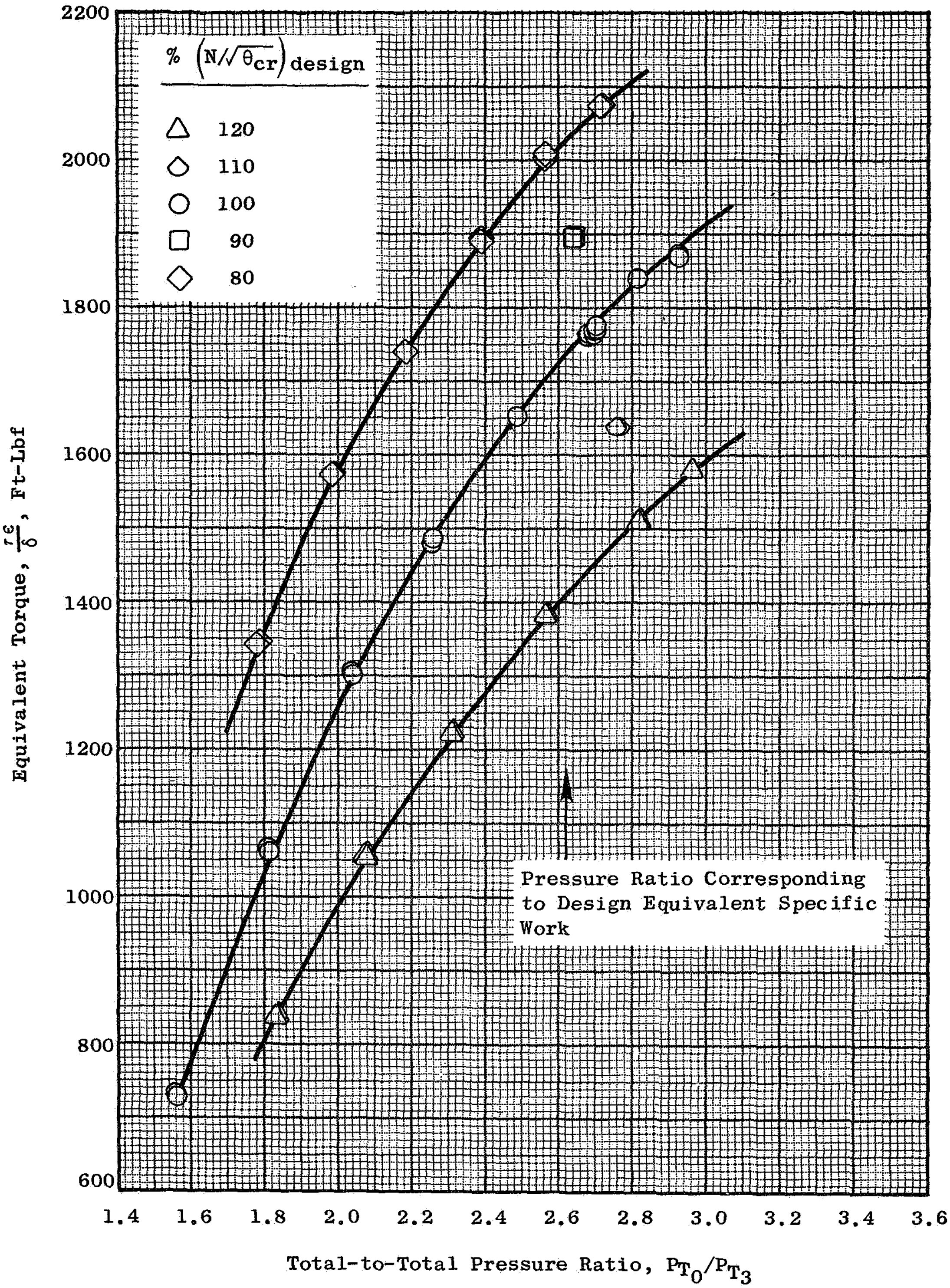


Figure 51. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 4 (PPTP).

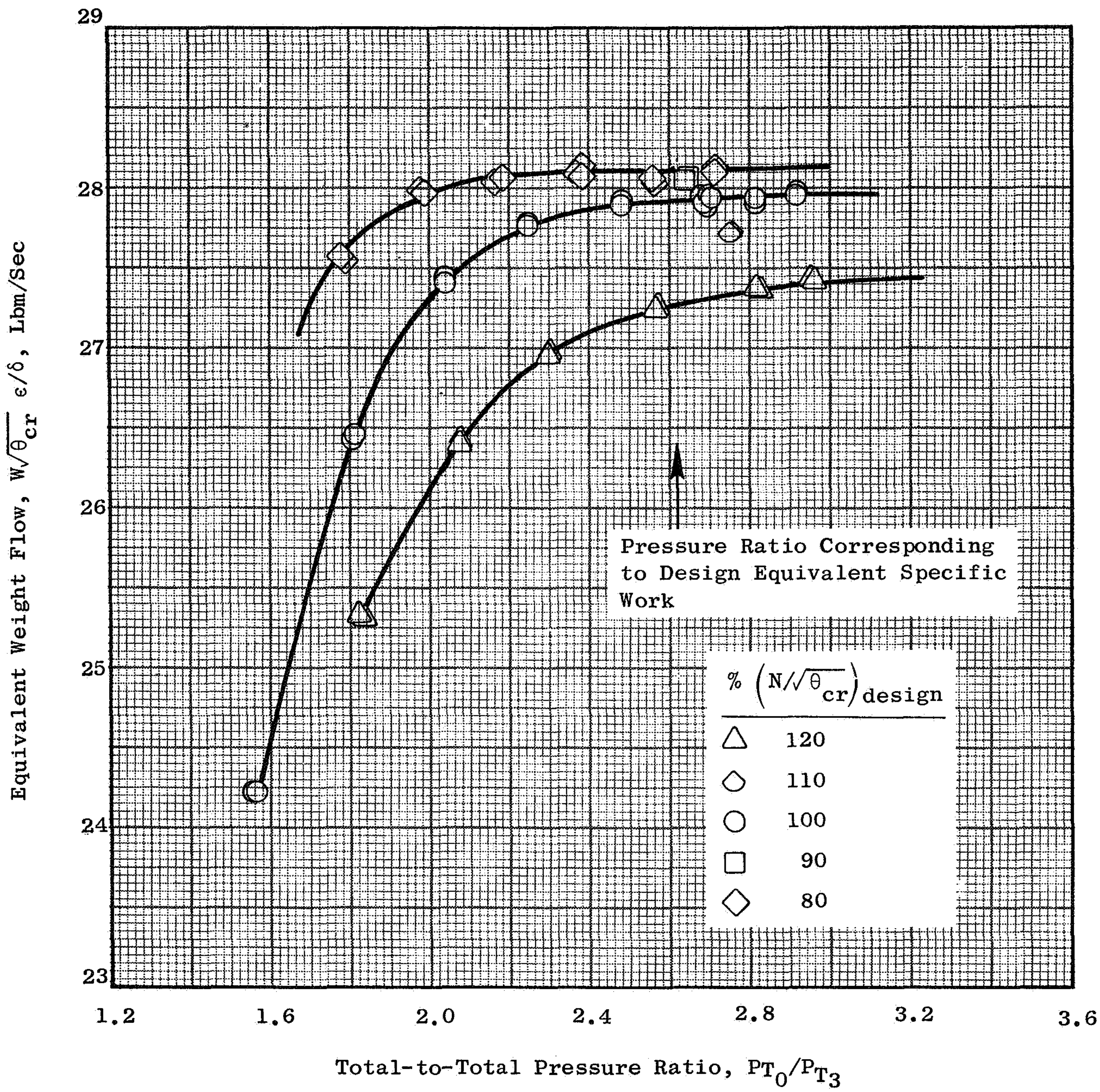


Figure 52. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 4 (PPTP).

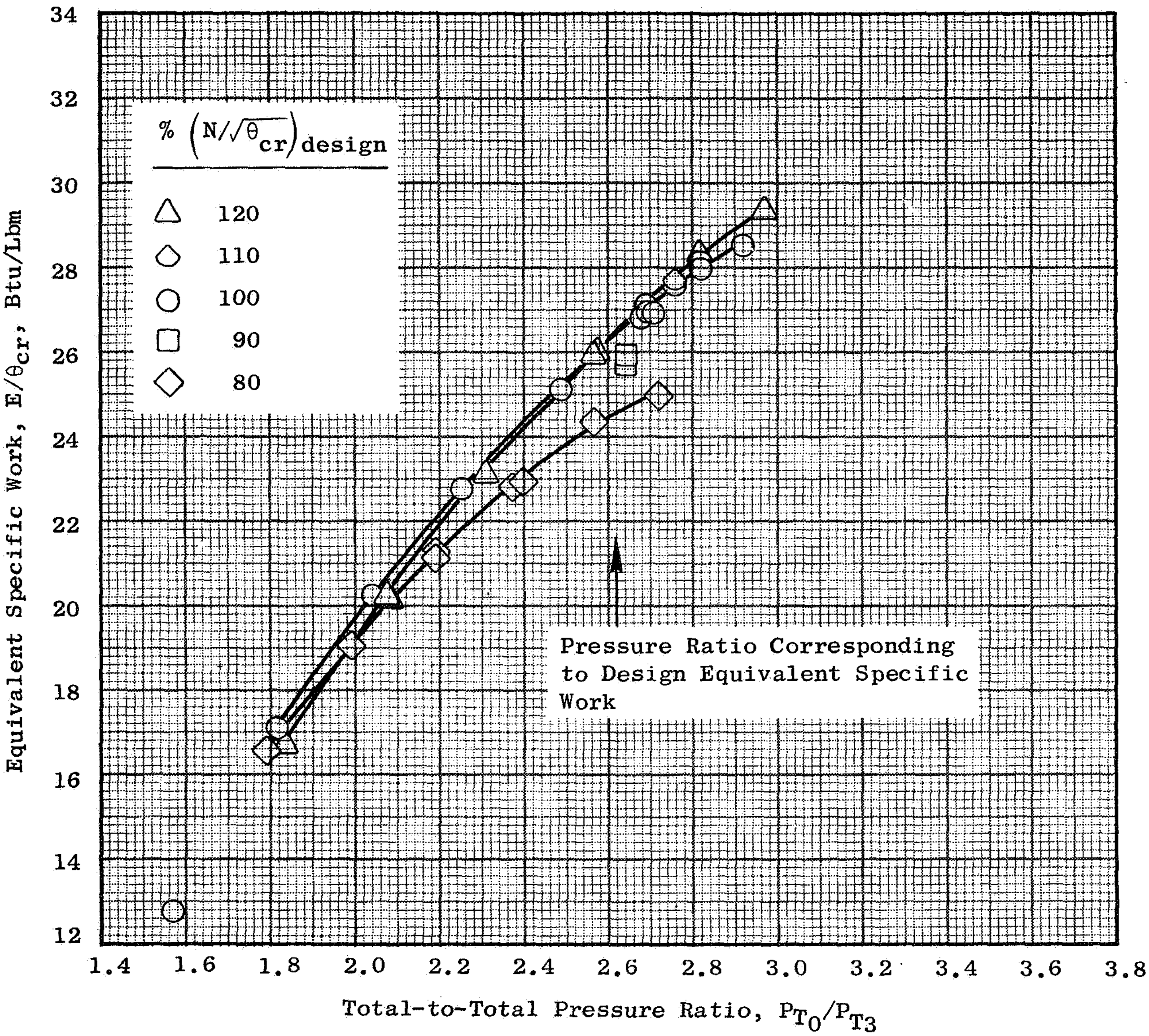


Figure 53. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 4 (PPTP).

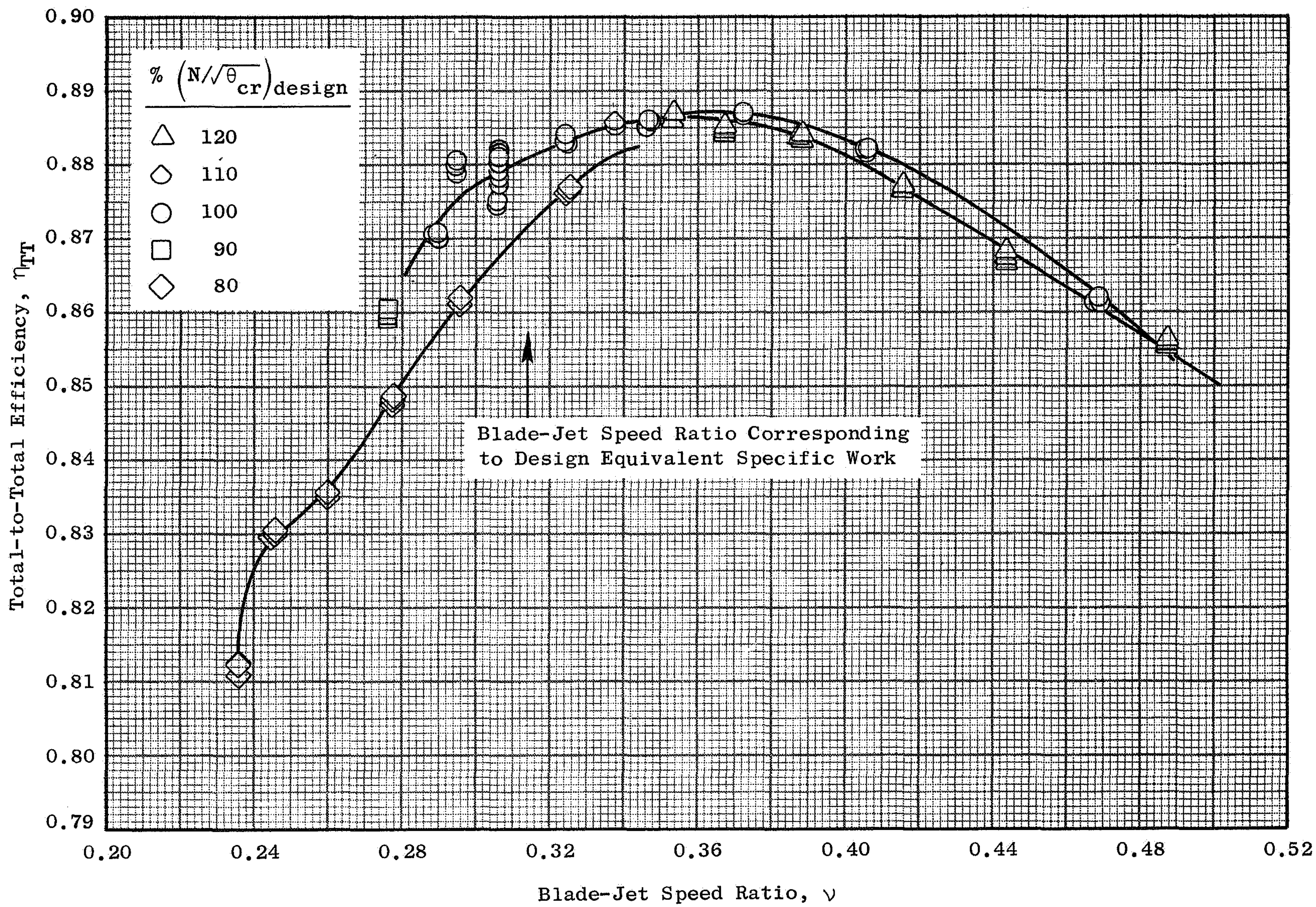


Figure 54. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 4 (PPTP).

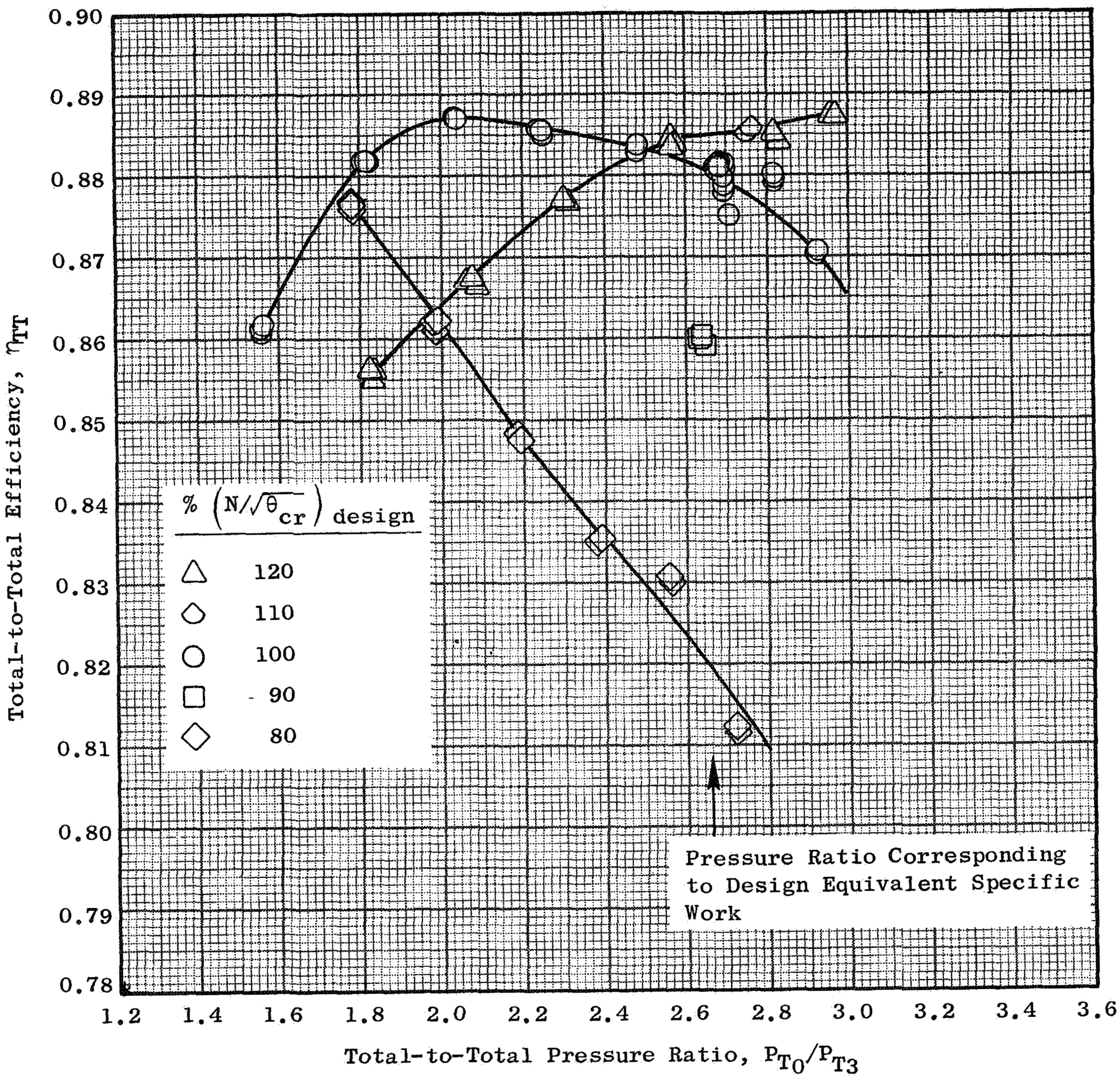


Figure 55. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 4 (PPTP).

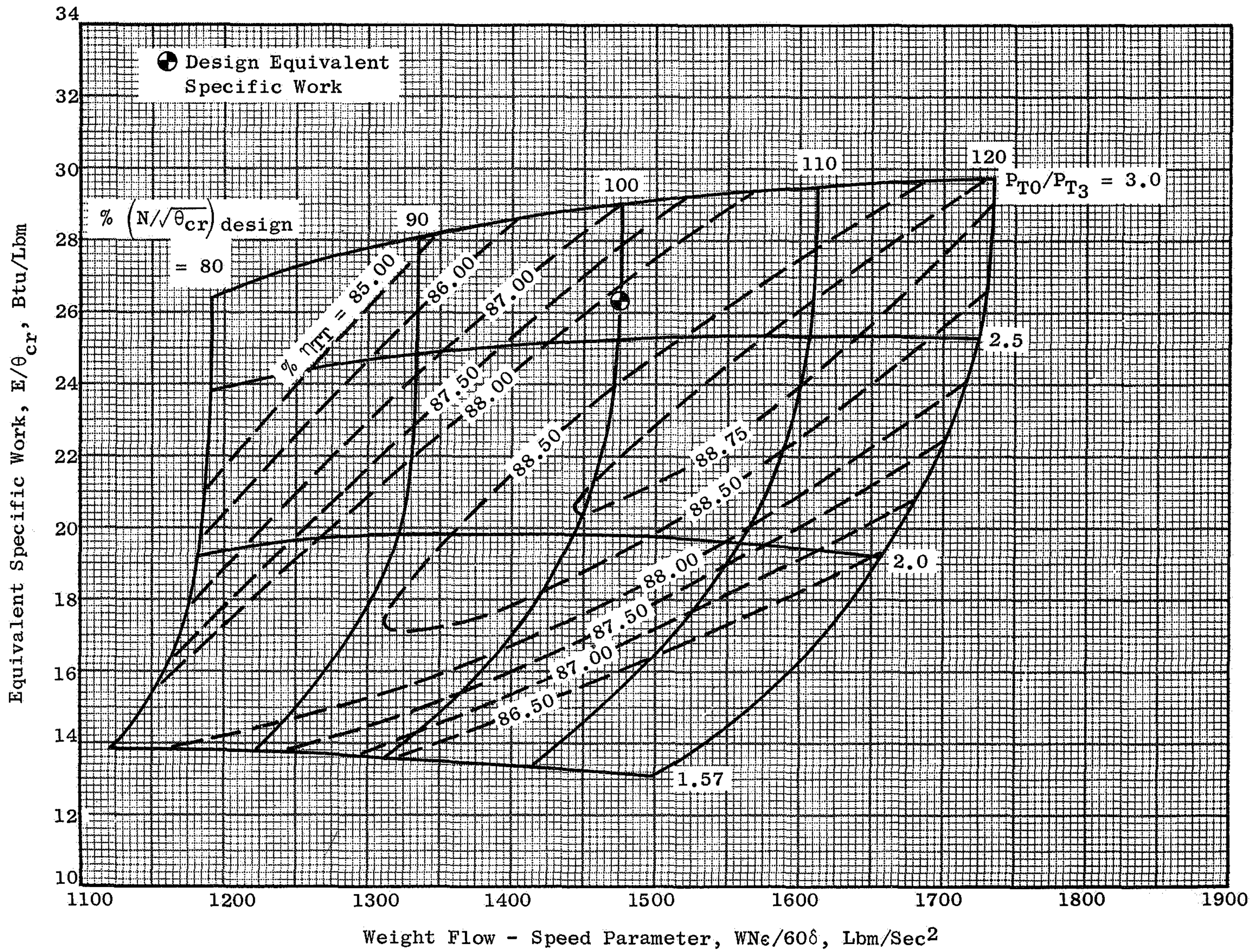


Figure 56. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 4 (PPTP).

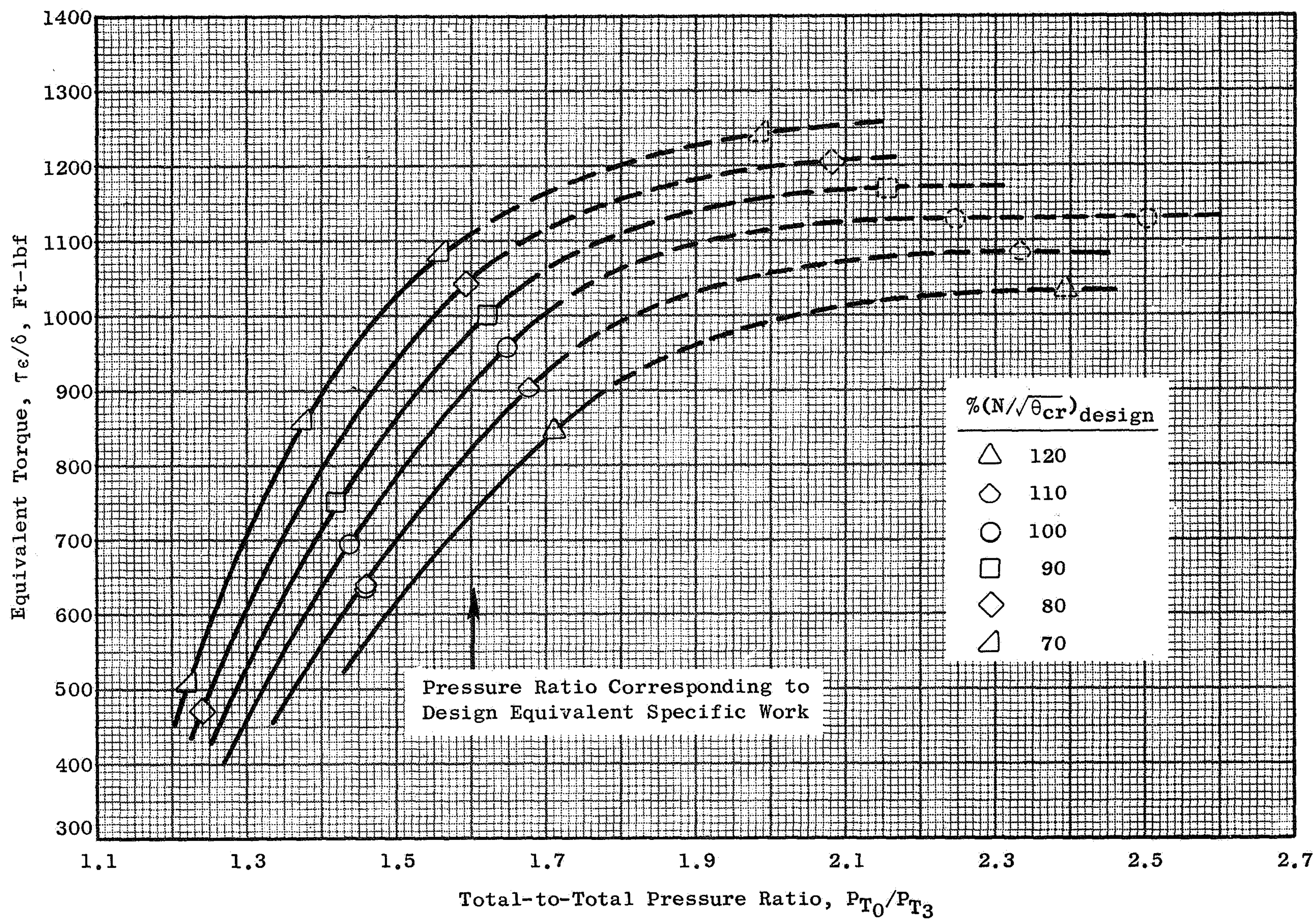


Figure 57. Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

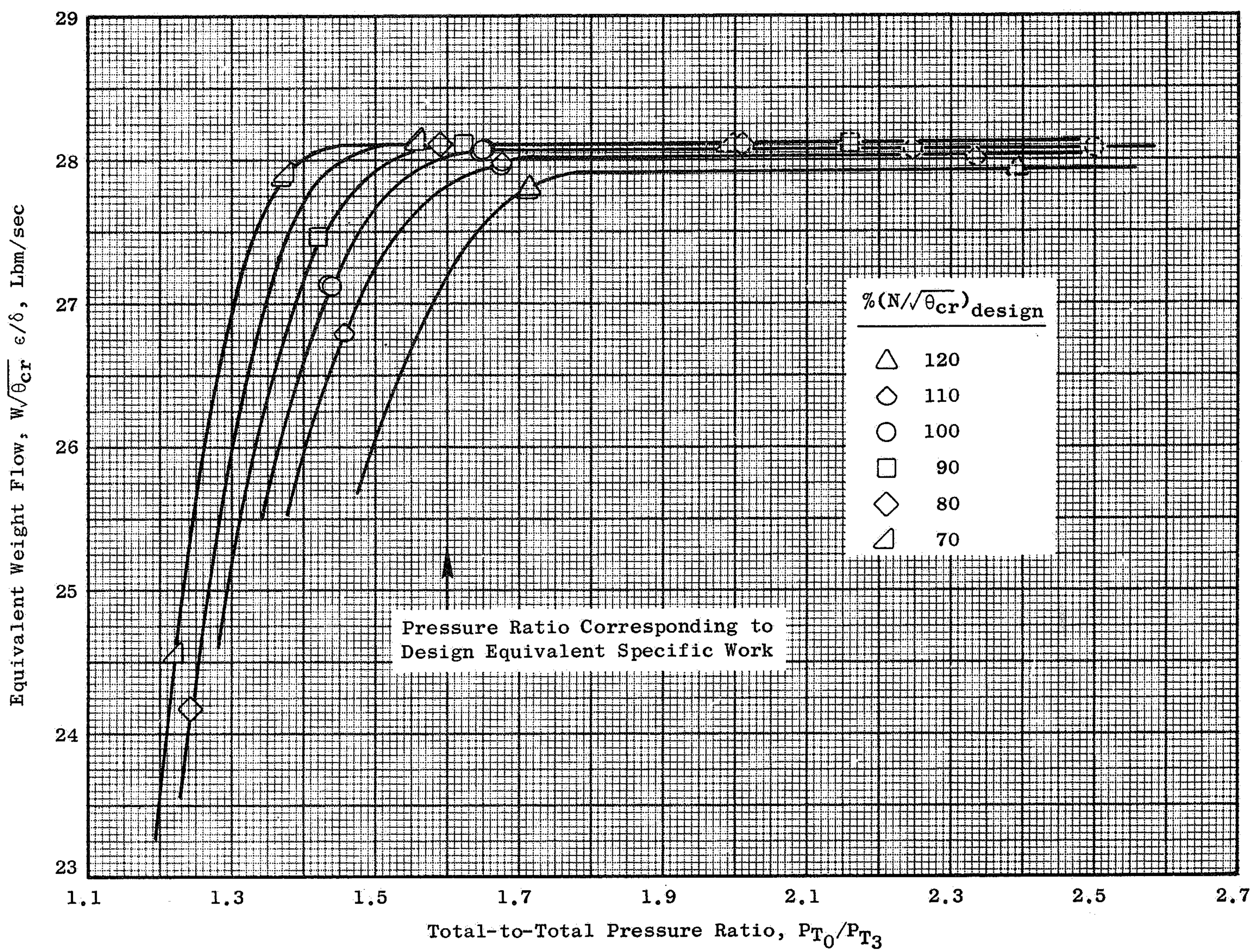


Figure 58. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

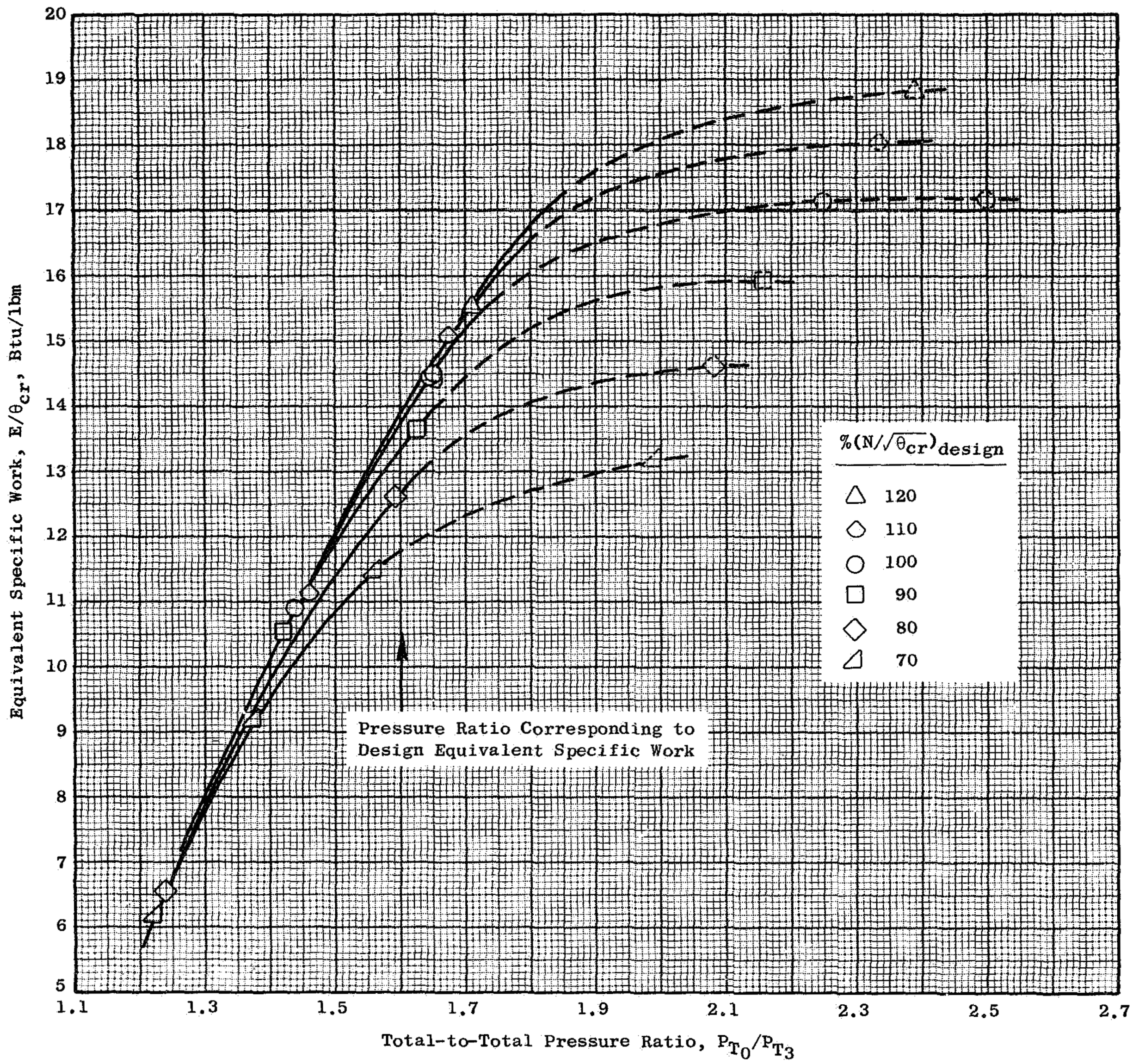


Figure 59. Equivalent Specific Work Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

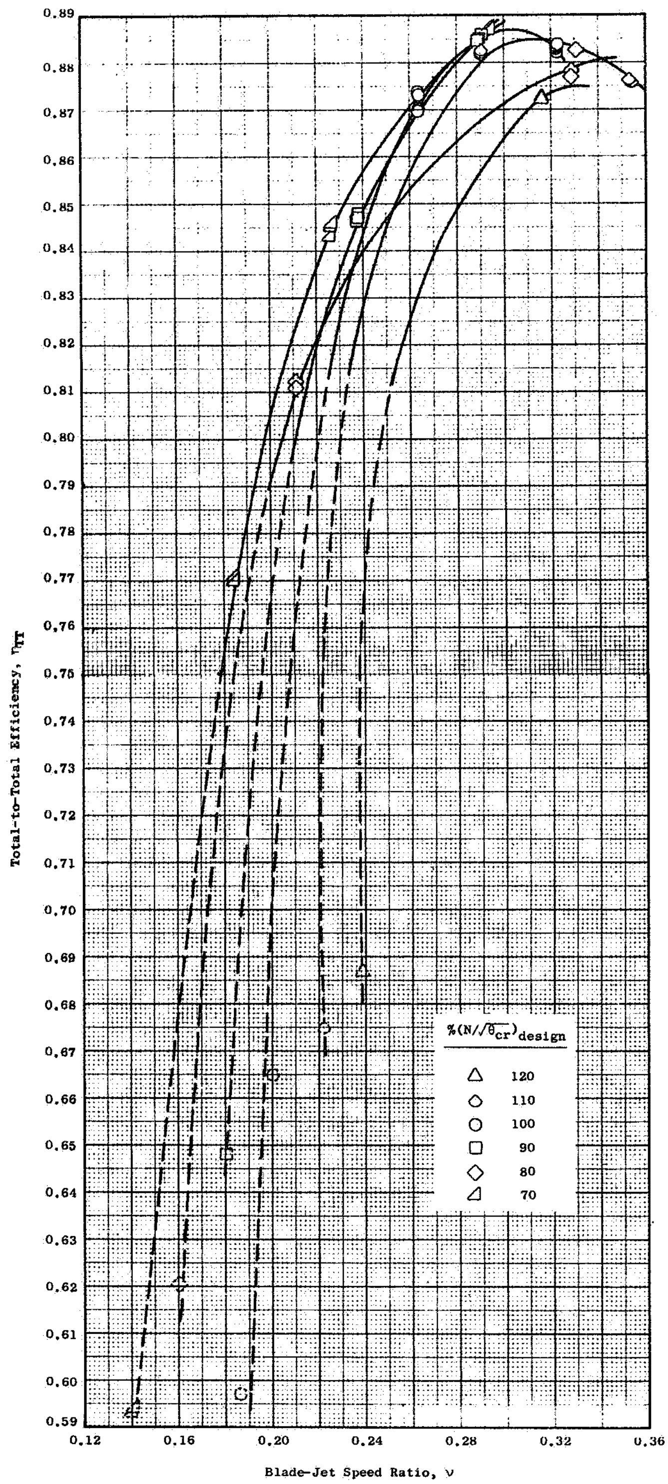


Figure 60. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 3 (PP).

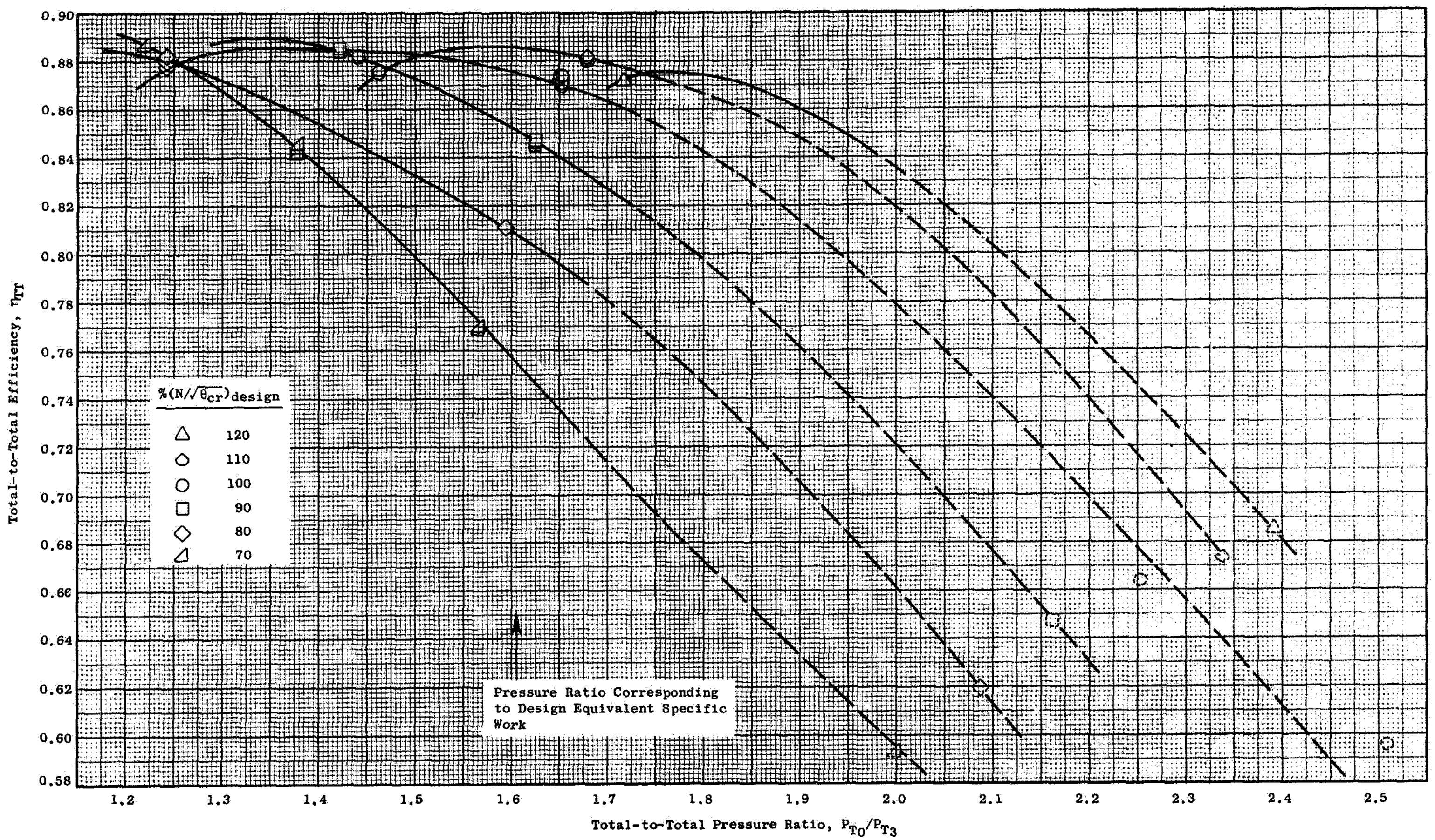


Figure 61. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

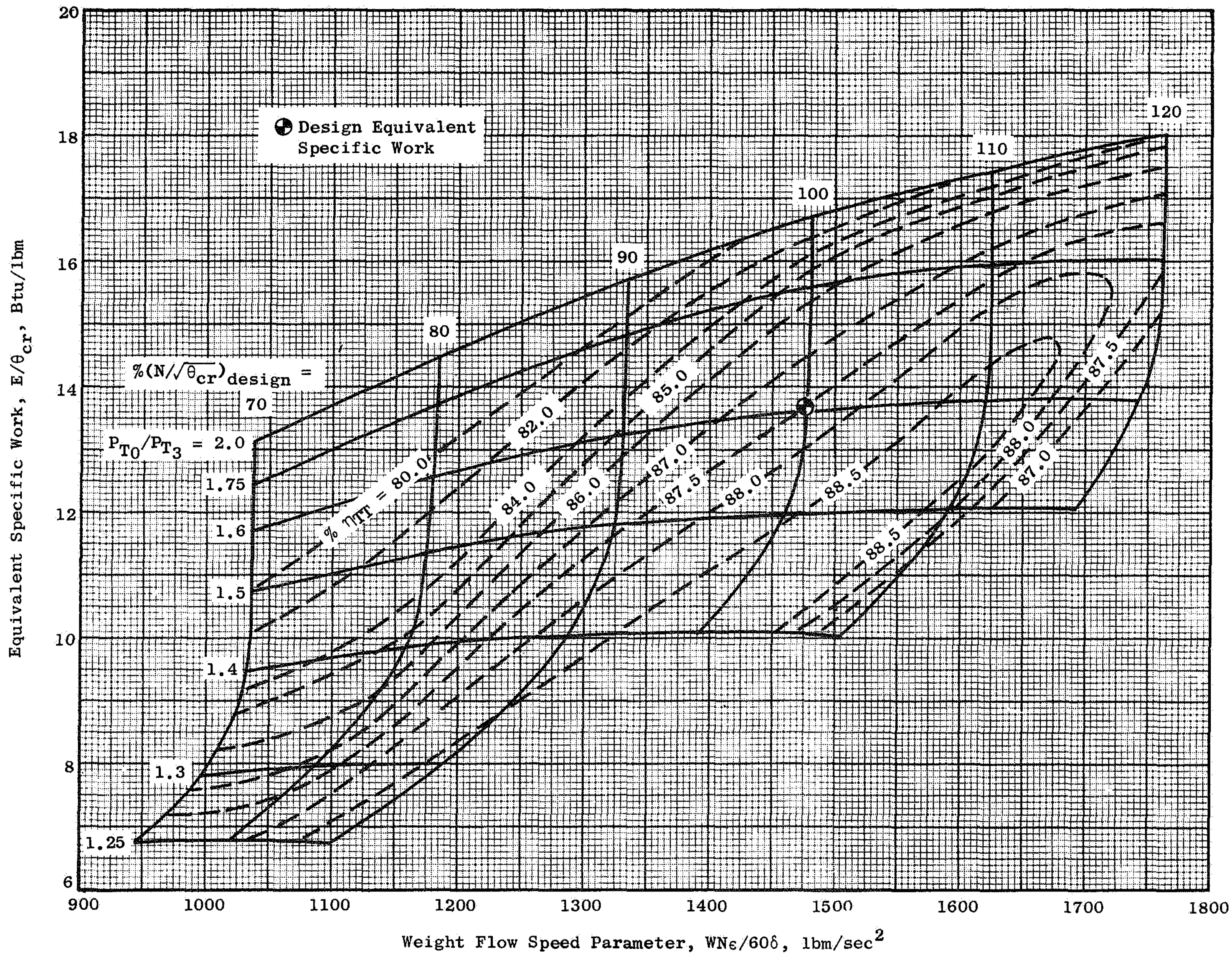


Figure 62. Equivalent Specific Work Vs. Weight Flow-Speed Parameter, Configuration 3 (PP).

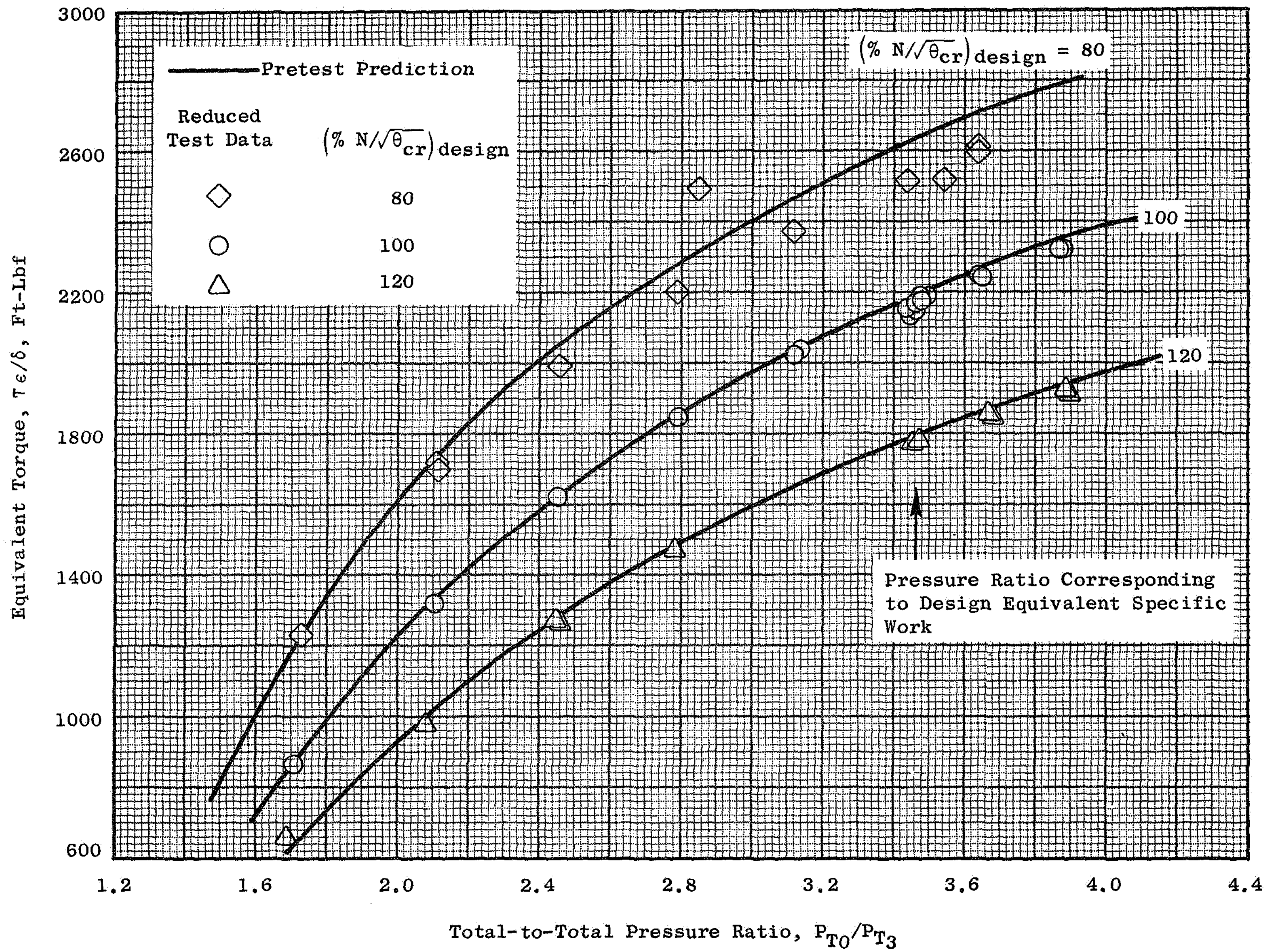


Figure 63. Predicted and Actual Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

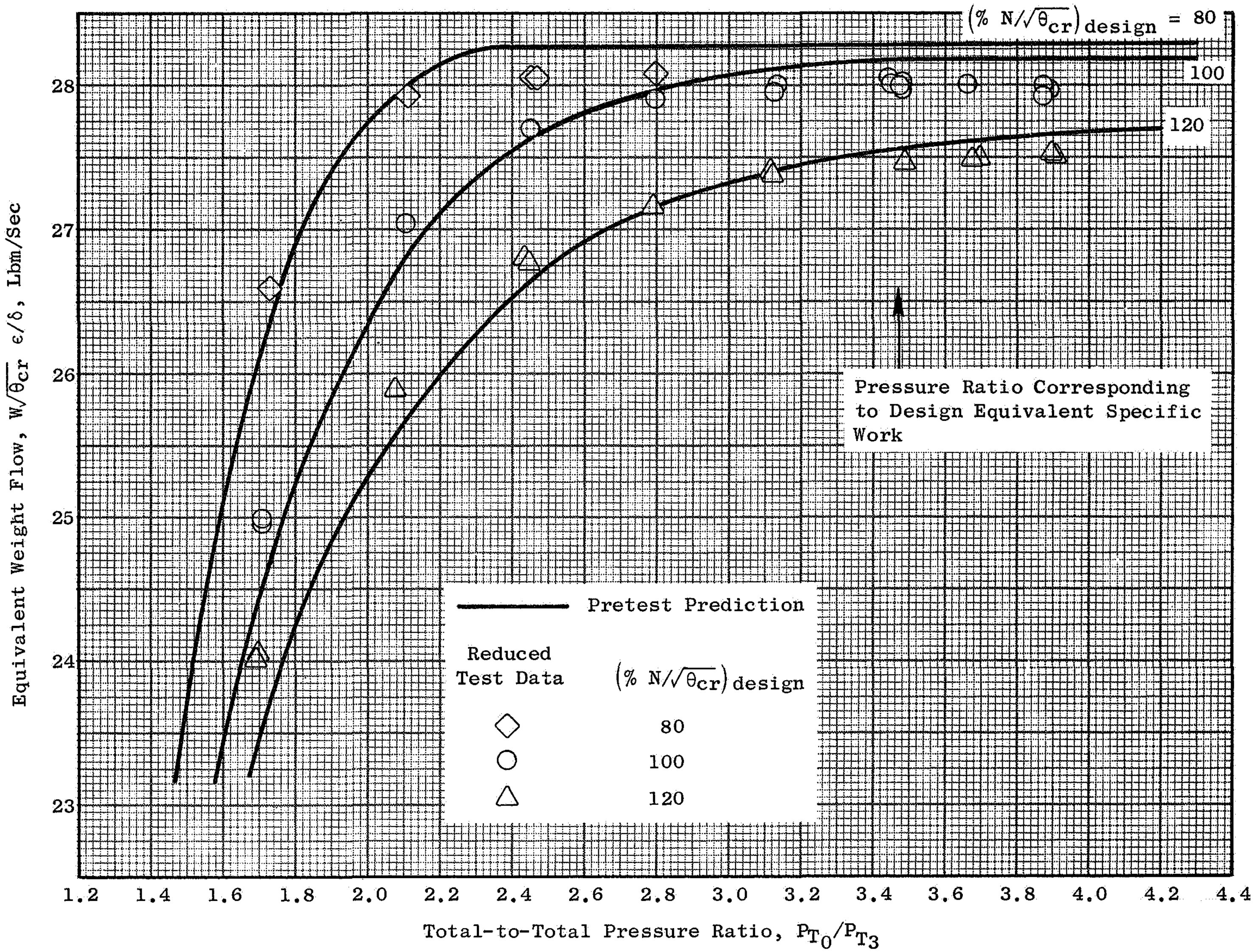


Figure 64. Predicted and Actual Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

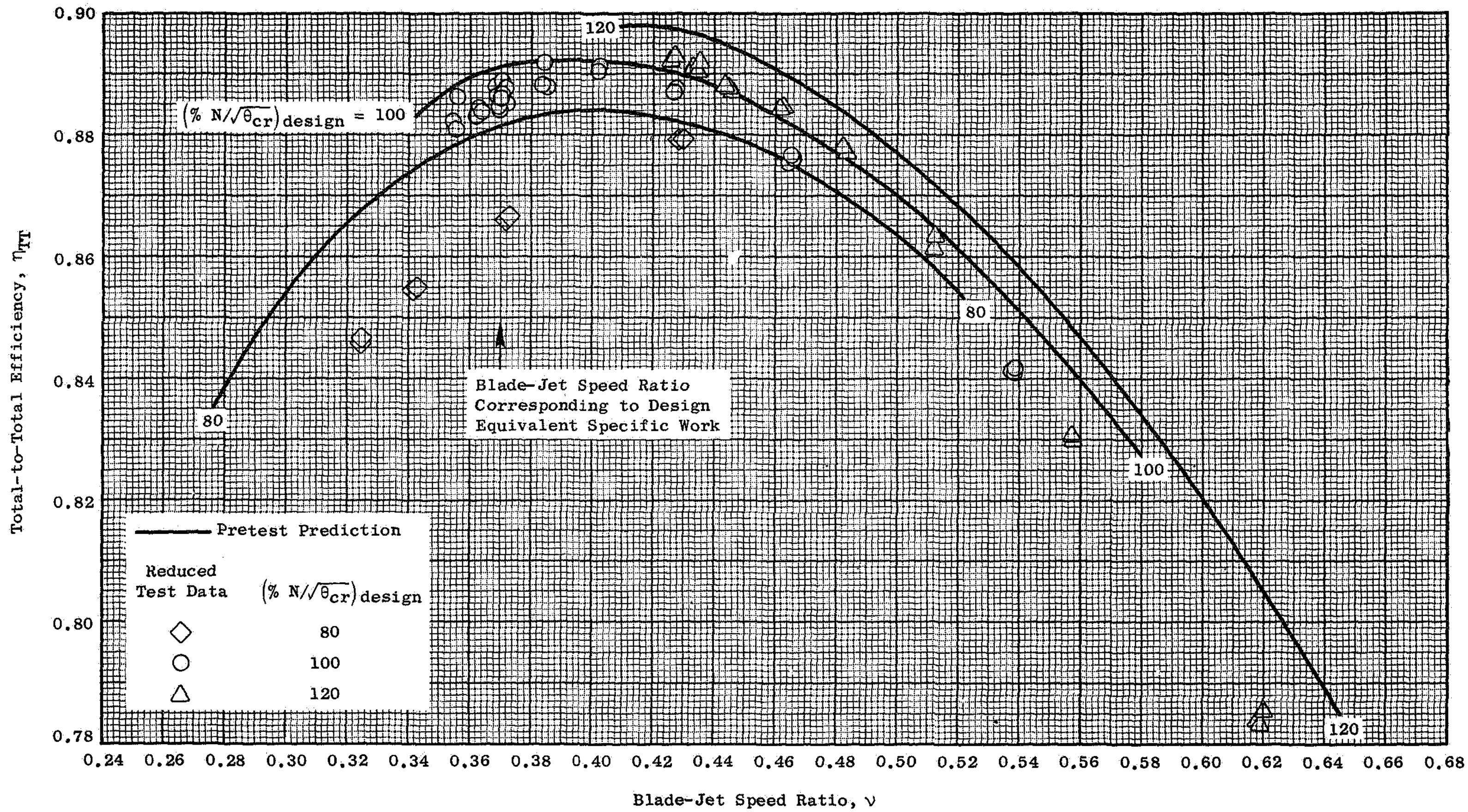


Figure 65. Predicted and Actual Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 1 (PPPPPP).

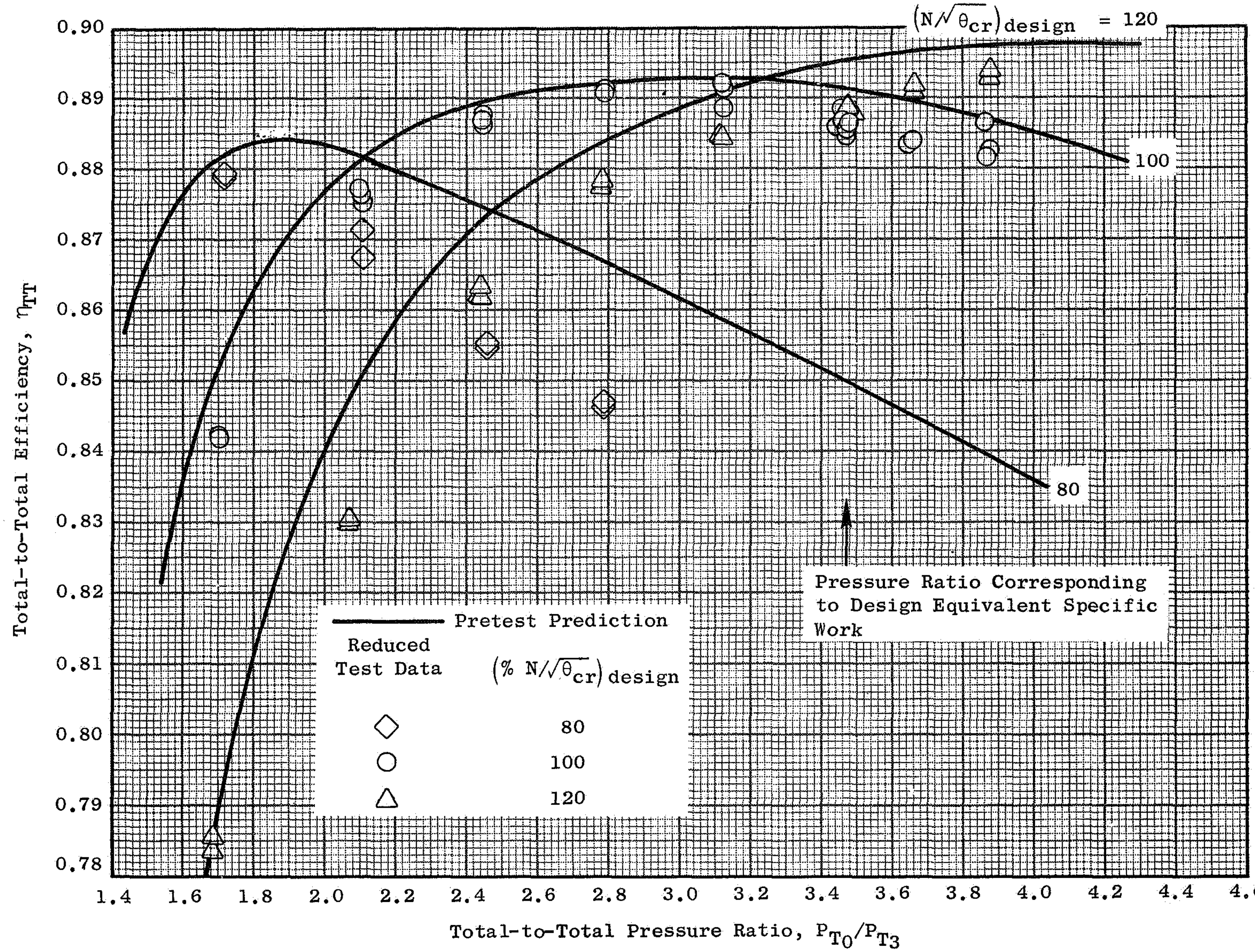


Figure 66. Predicted and Actual Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 1 (PPPPPP).

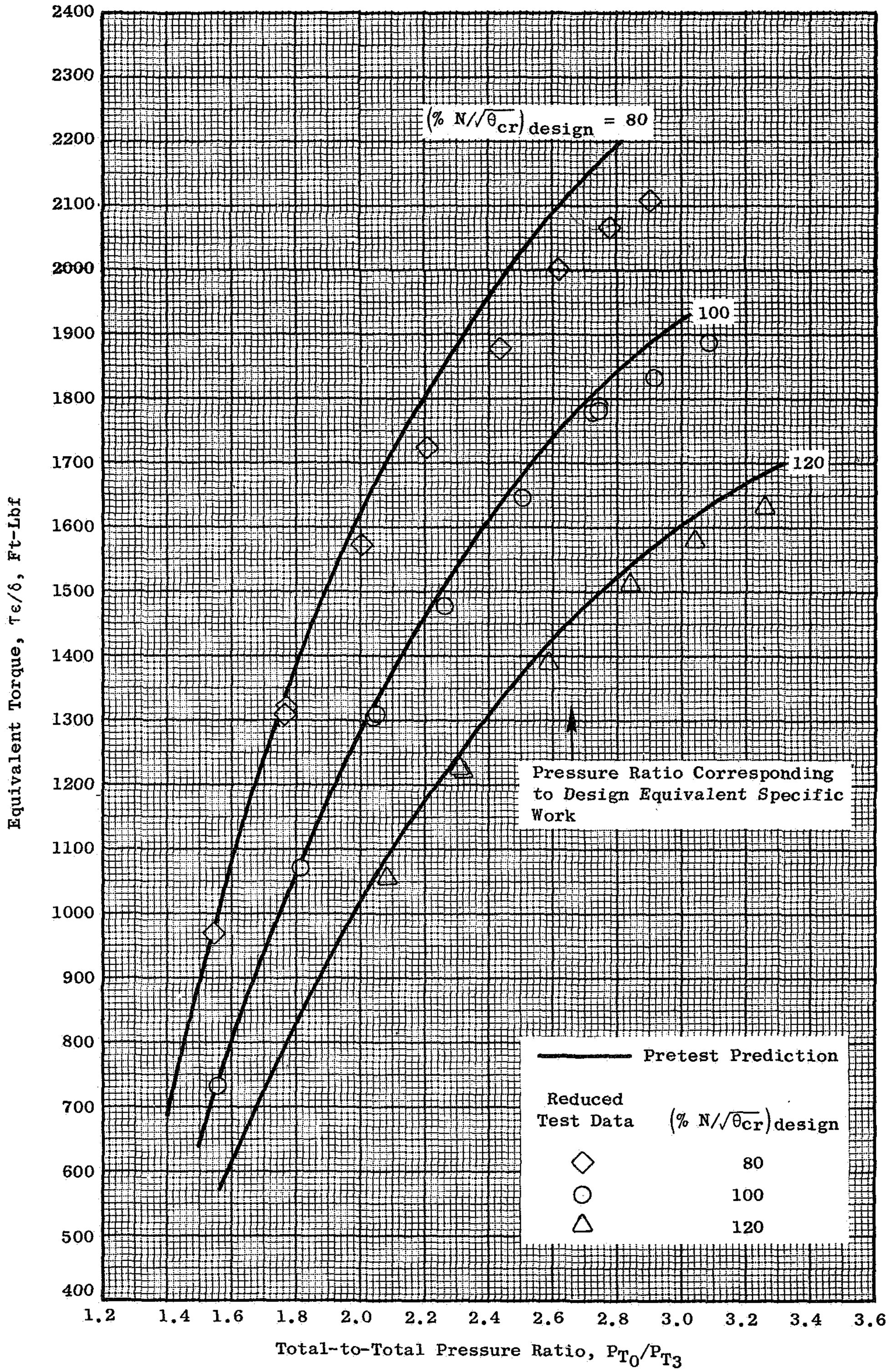


Figure 67. Predicted and Actual Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

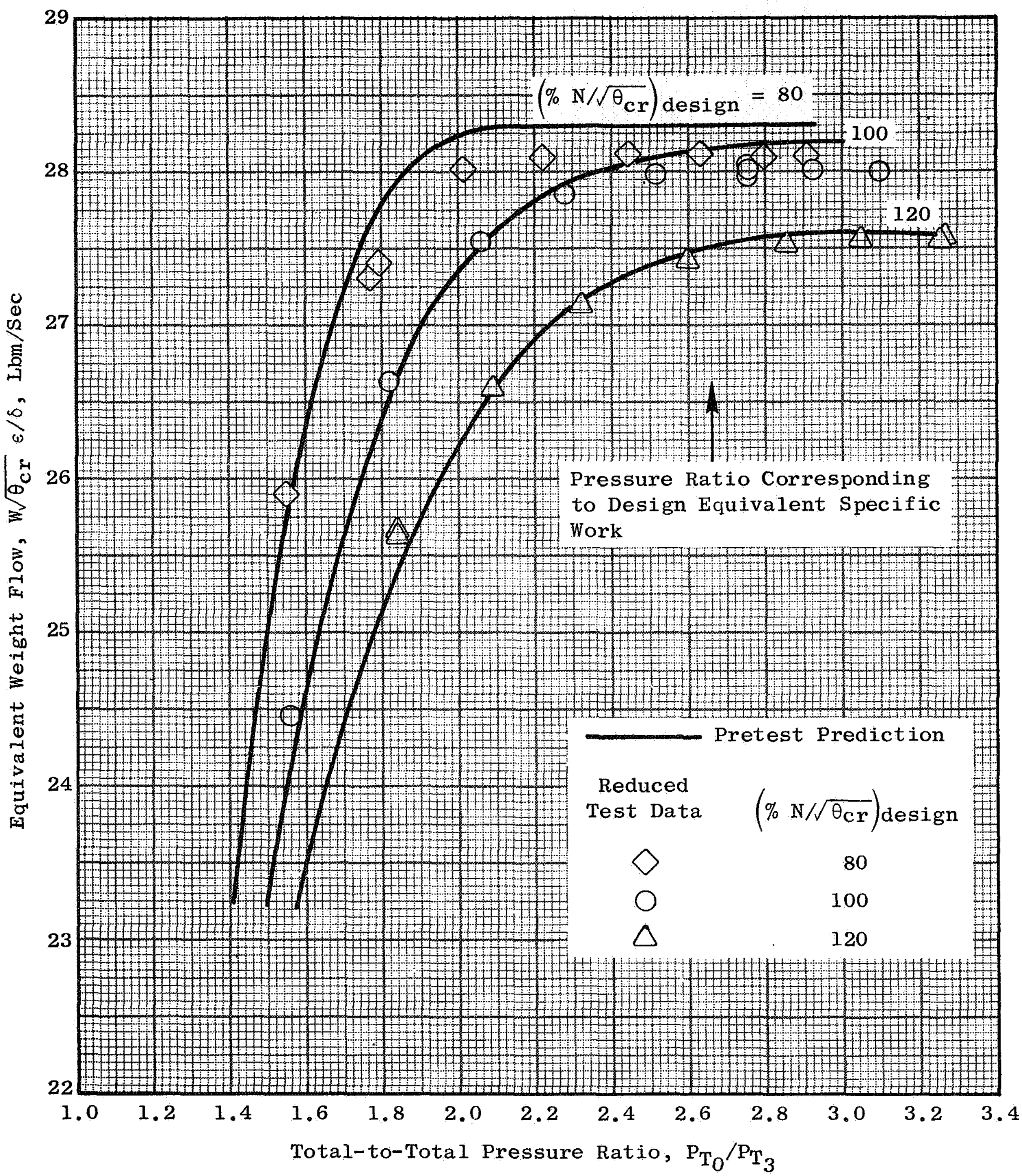


Figure 68. Predicted and Actual Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

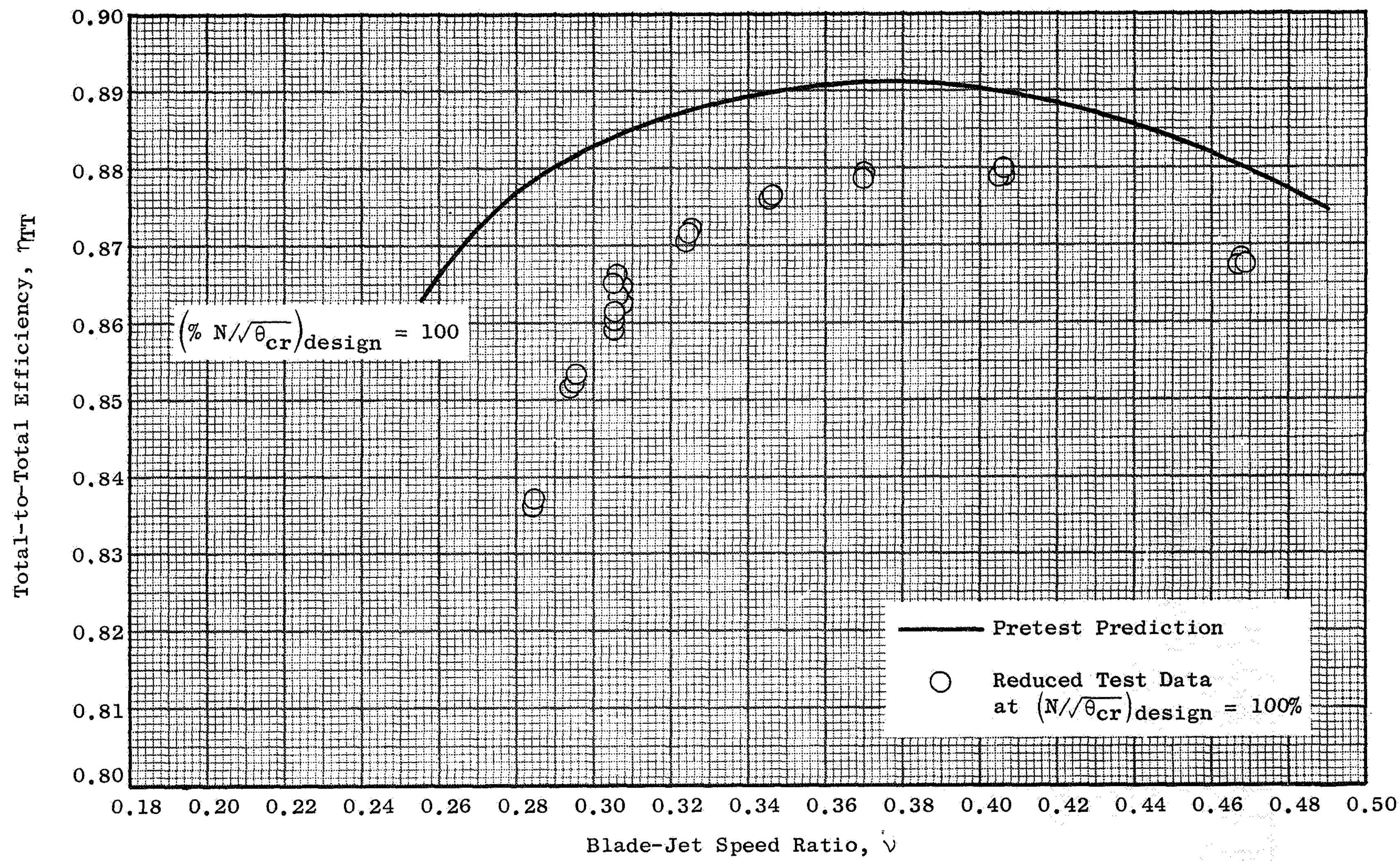


Figure 69. Predicted and Actual Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 2 (PPPP).

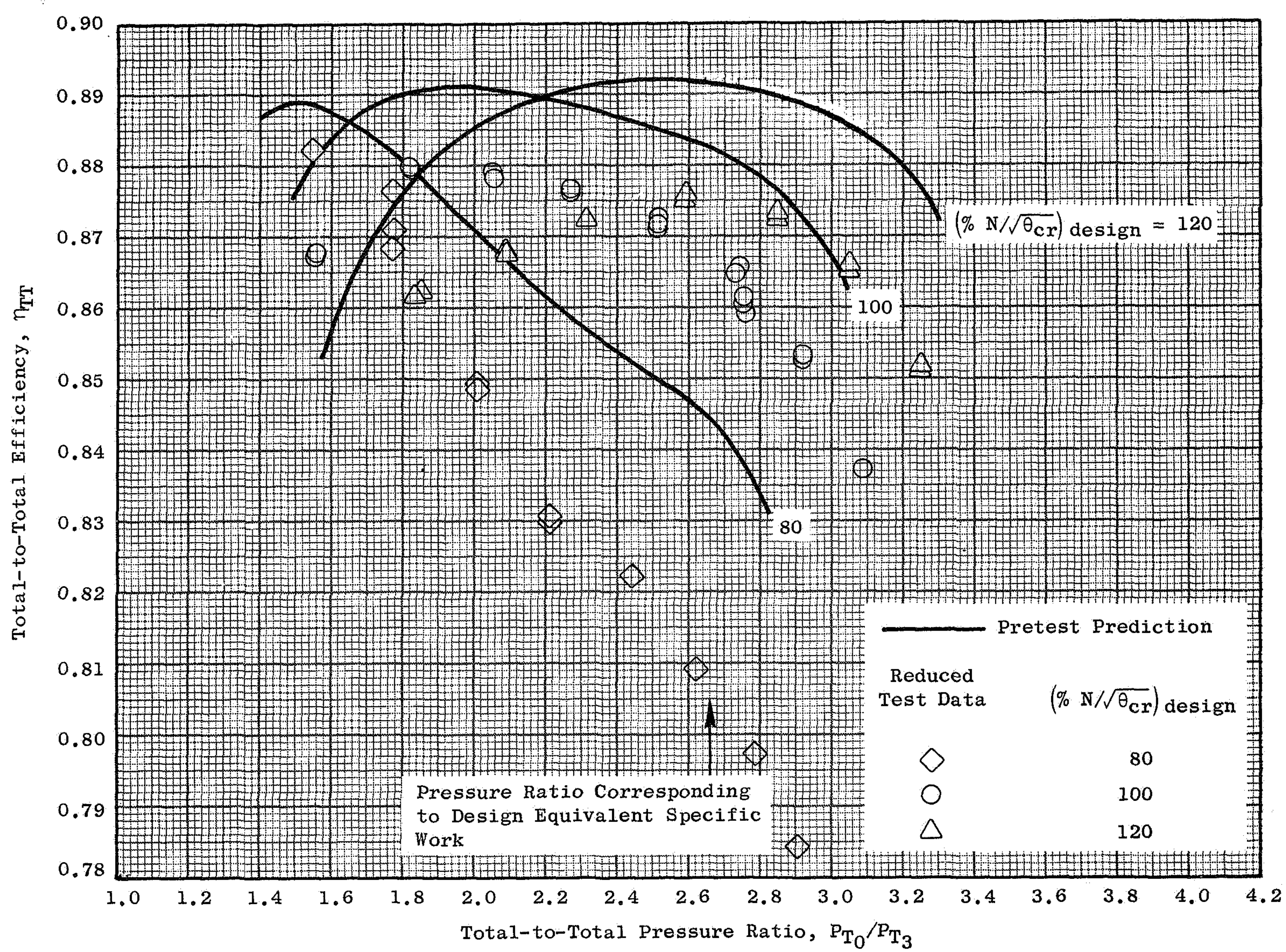


Figure 70. Predicted and Actual Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 2 (PPPP).

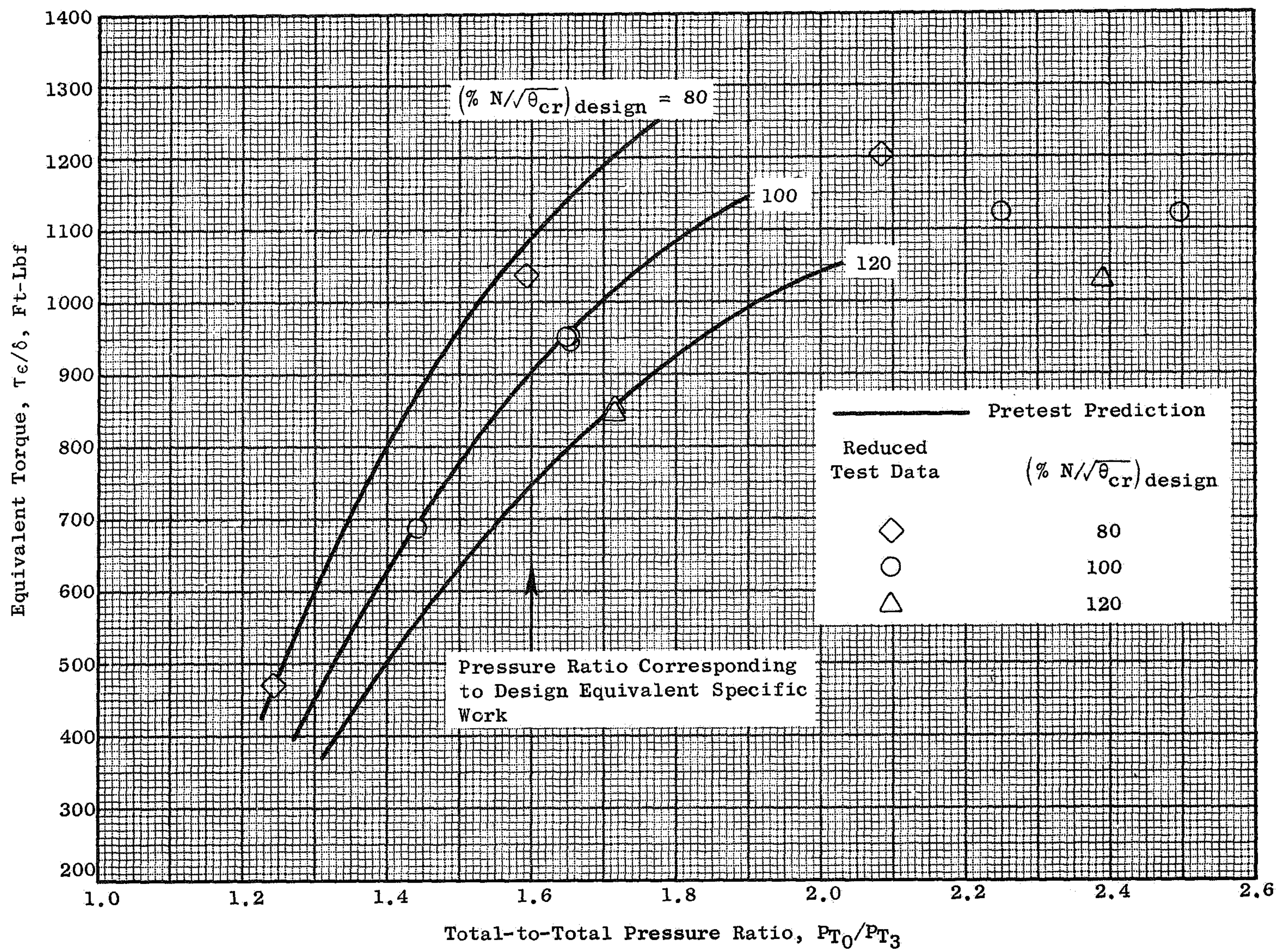


Figure 71. Predicted and Actual Equivalent Torque Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

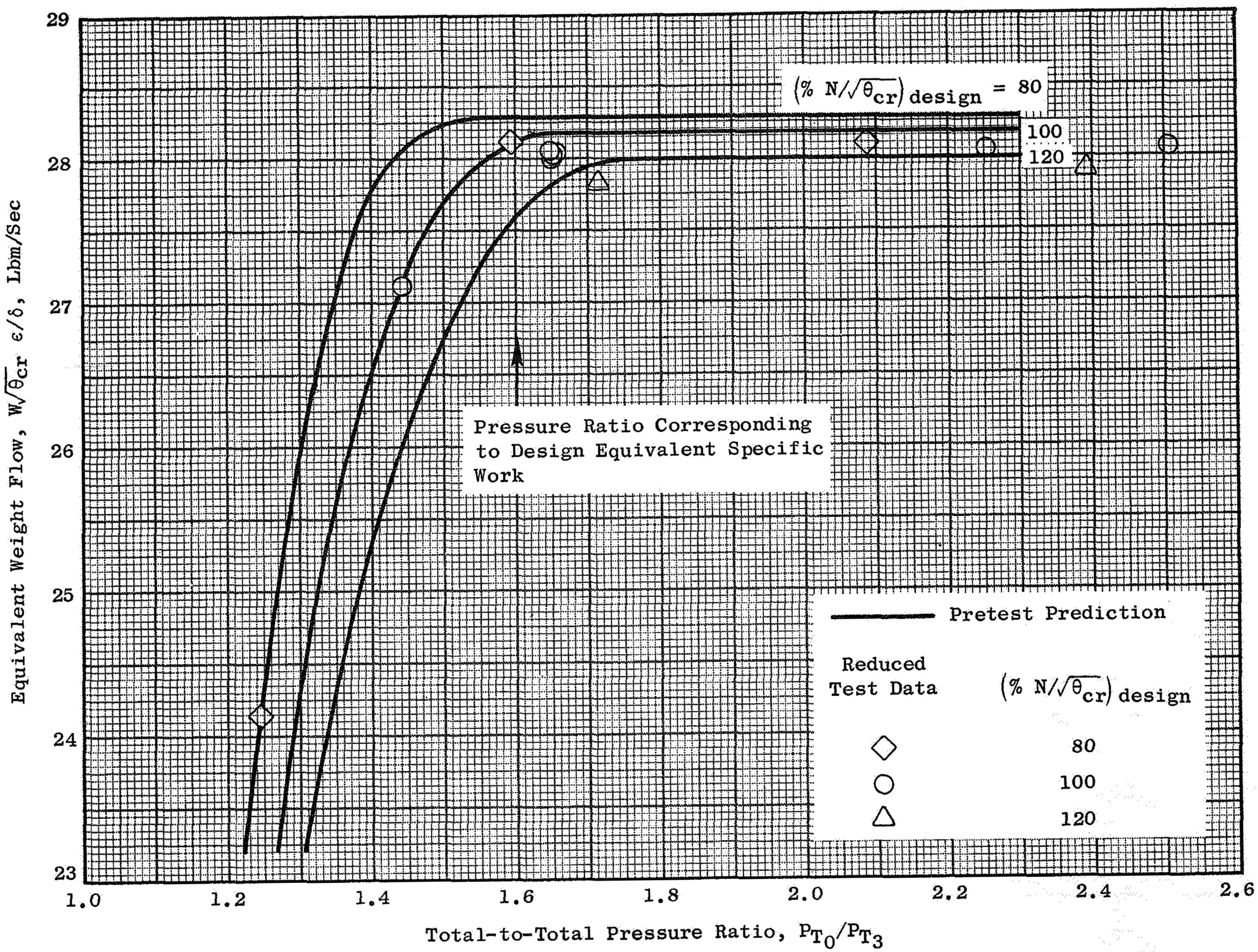


Figure 72. Predicted and Actual Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

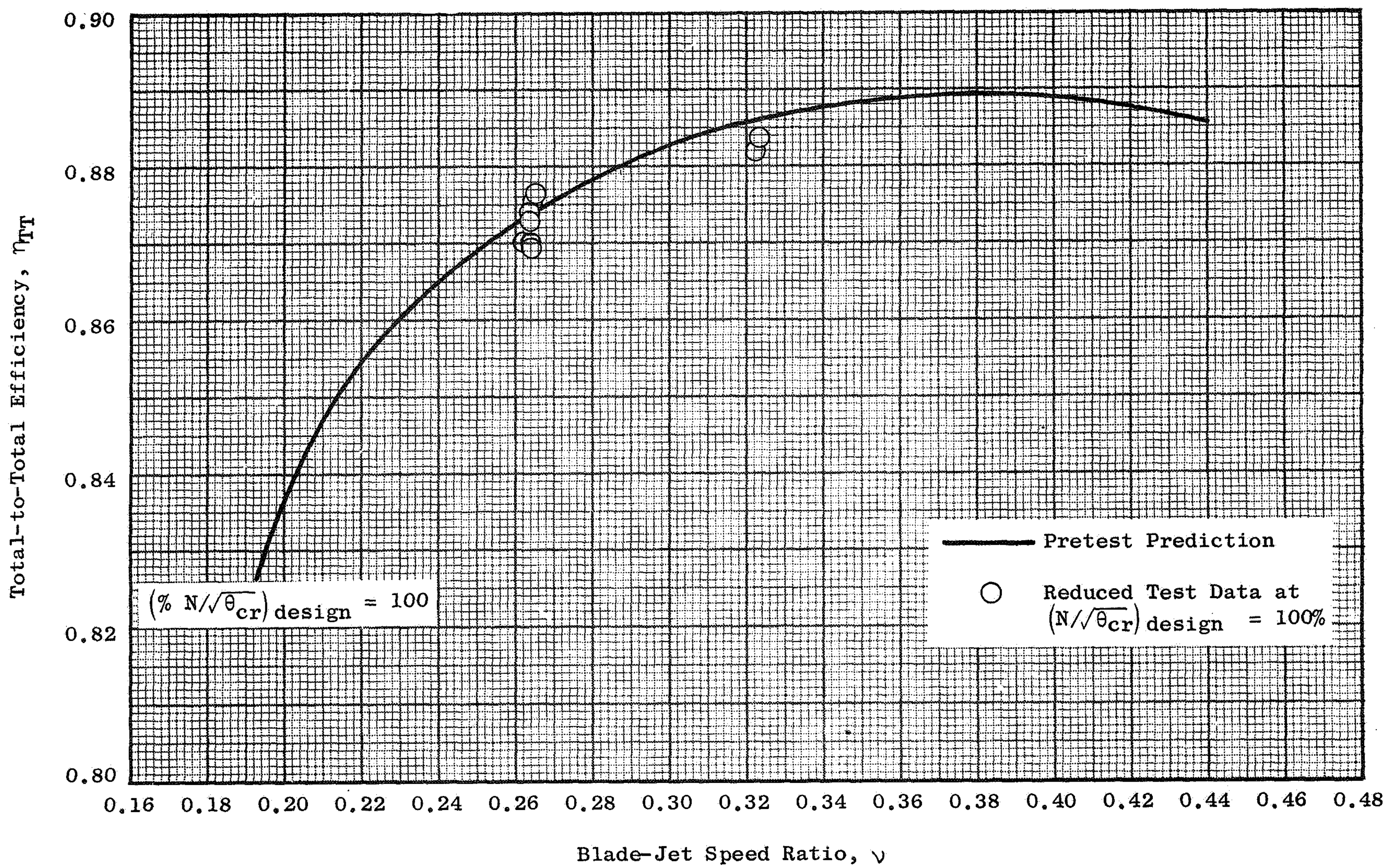


Figure 73. Predicted and Actual Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio, Configuration 3 (PP).

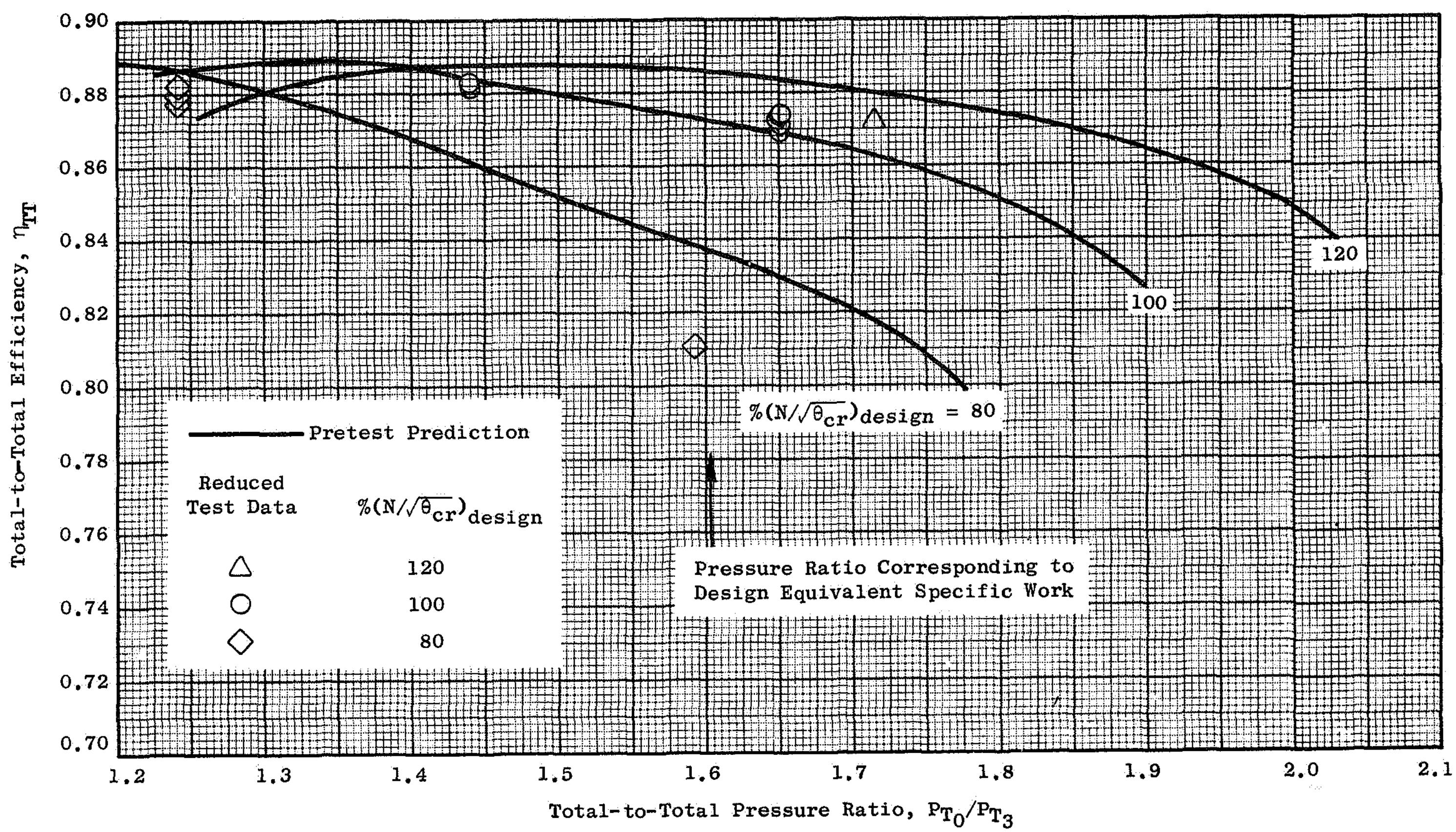


Figure 74. Predicted and Actual Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio, Configuration 3 (PP).

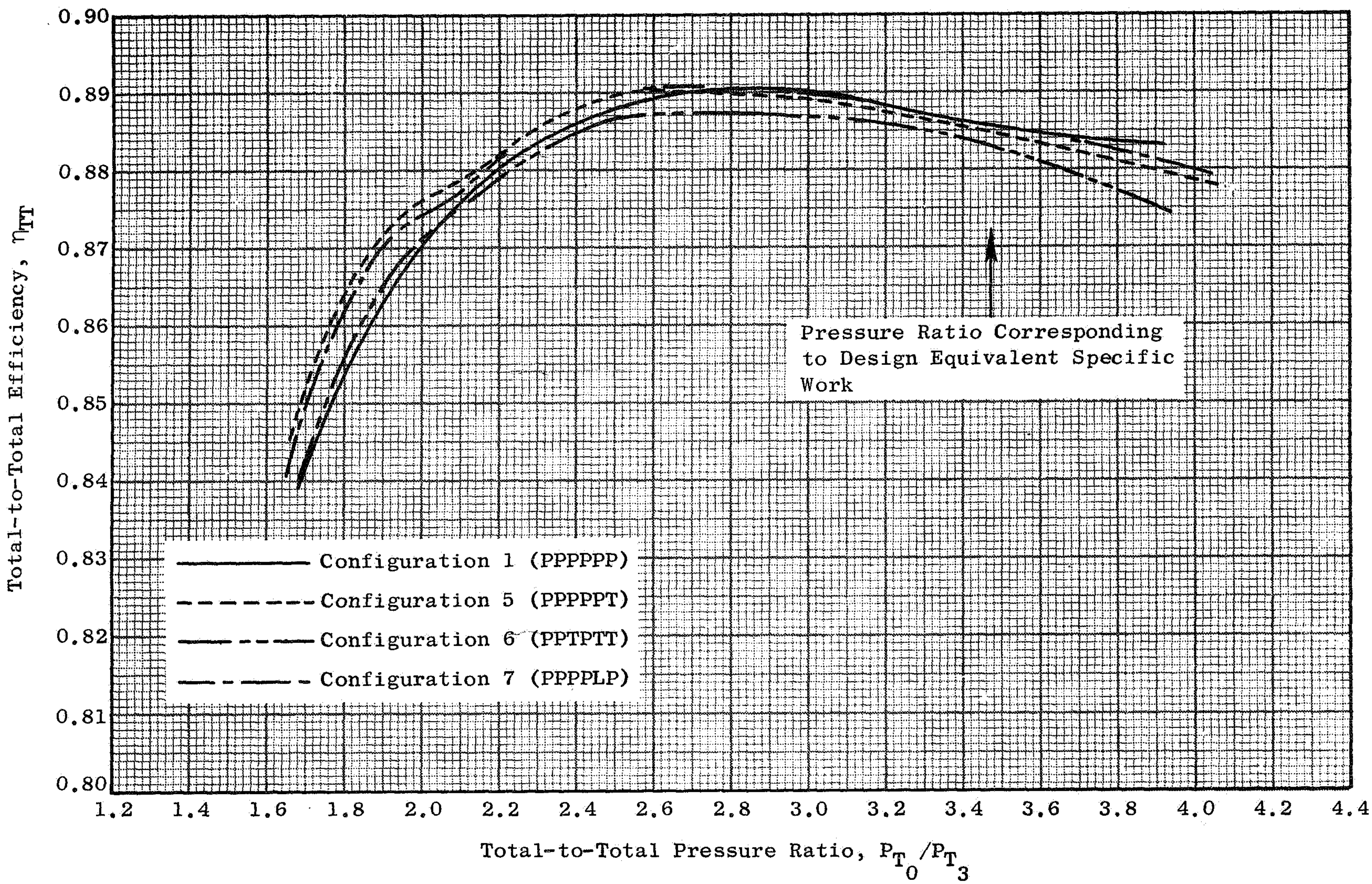


Figure 75. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio at Design Equivalent Speed, Three-Stage Turbine Configurations.

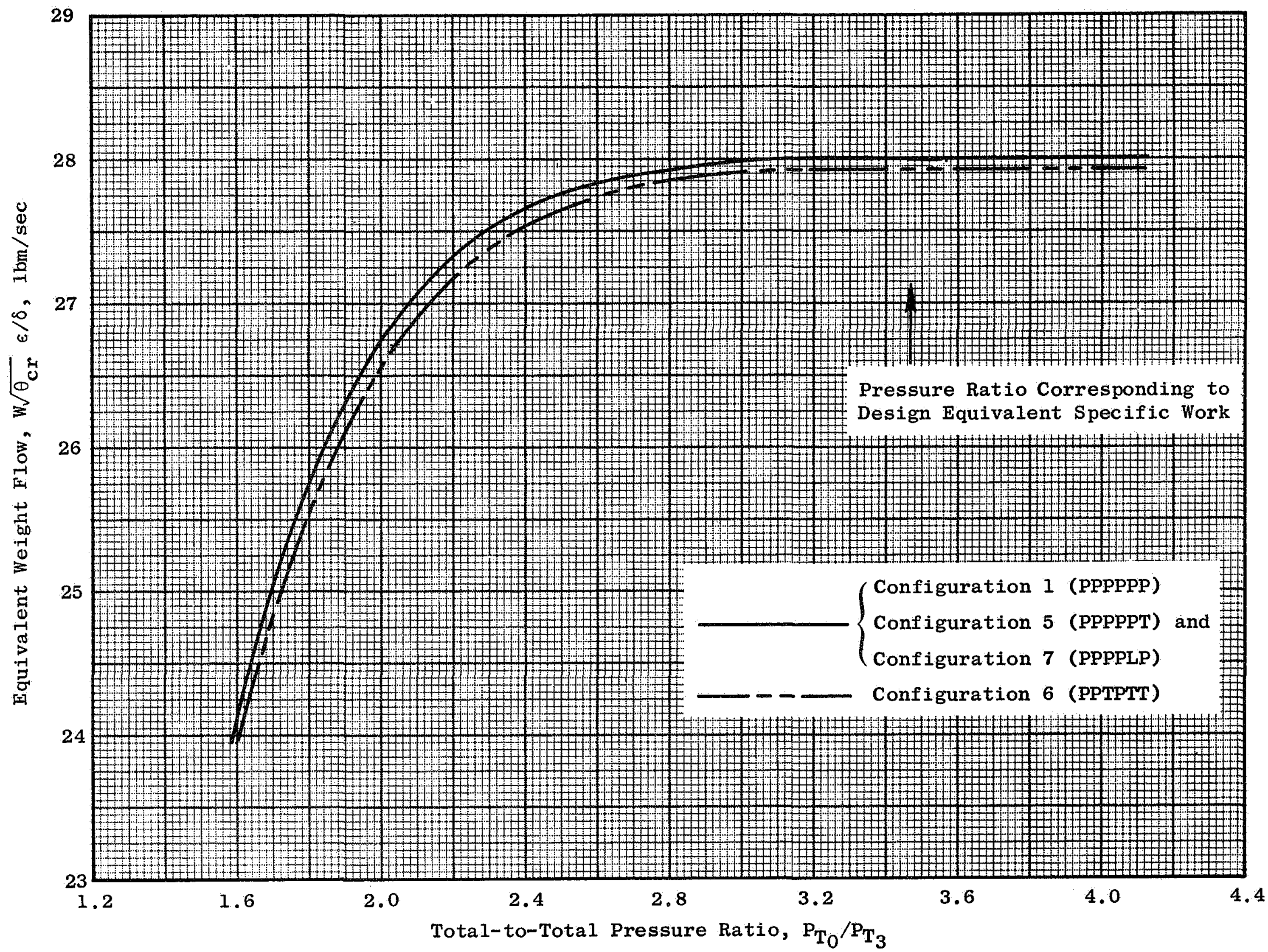


Figure 76. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio at Design Equivalent Speed, Three-Stage Turbine Configurations.

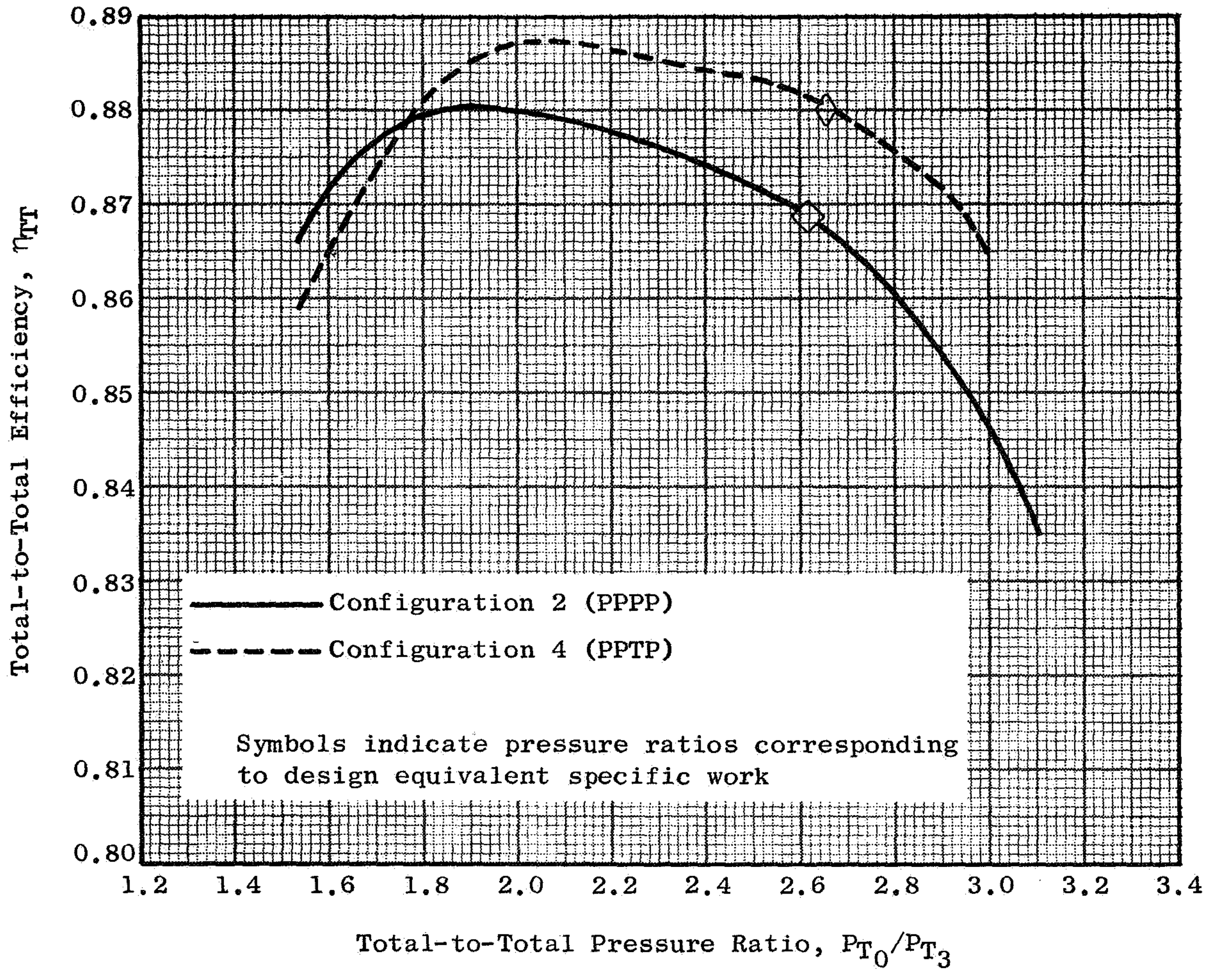


Figure 77. Total-to-Total Efficiency Vs. Total-to-Total Pressure Ratio at Design Equivalent Speed, Two-Stage Turbine Configurations.

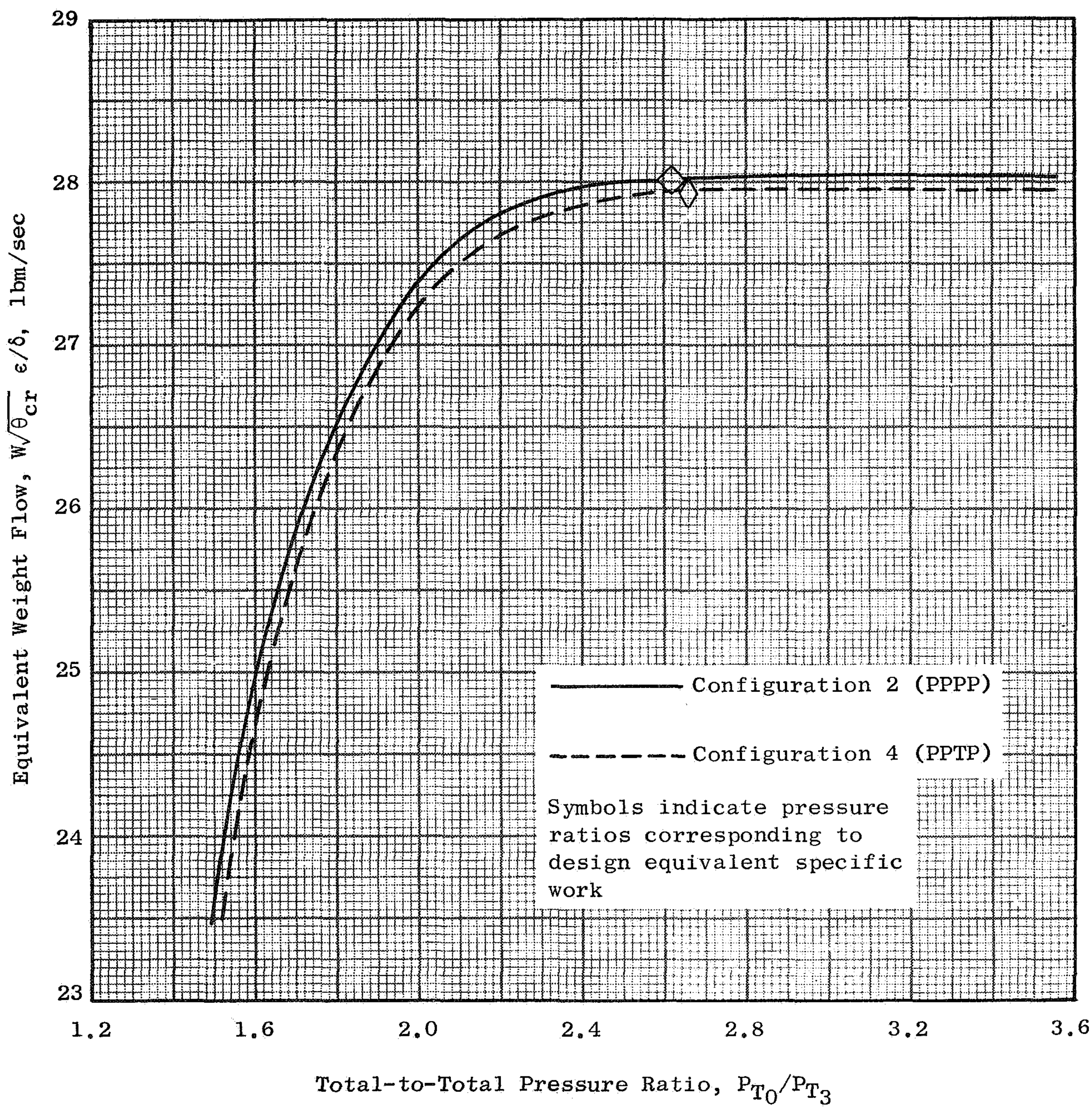


Figure 78. Equivalent Weight Flow Vs. Total-to-Total Pressure Ratio at Design Equivalent Speed, Two-Stage Turbine Configurations.

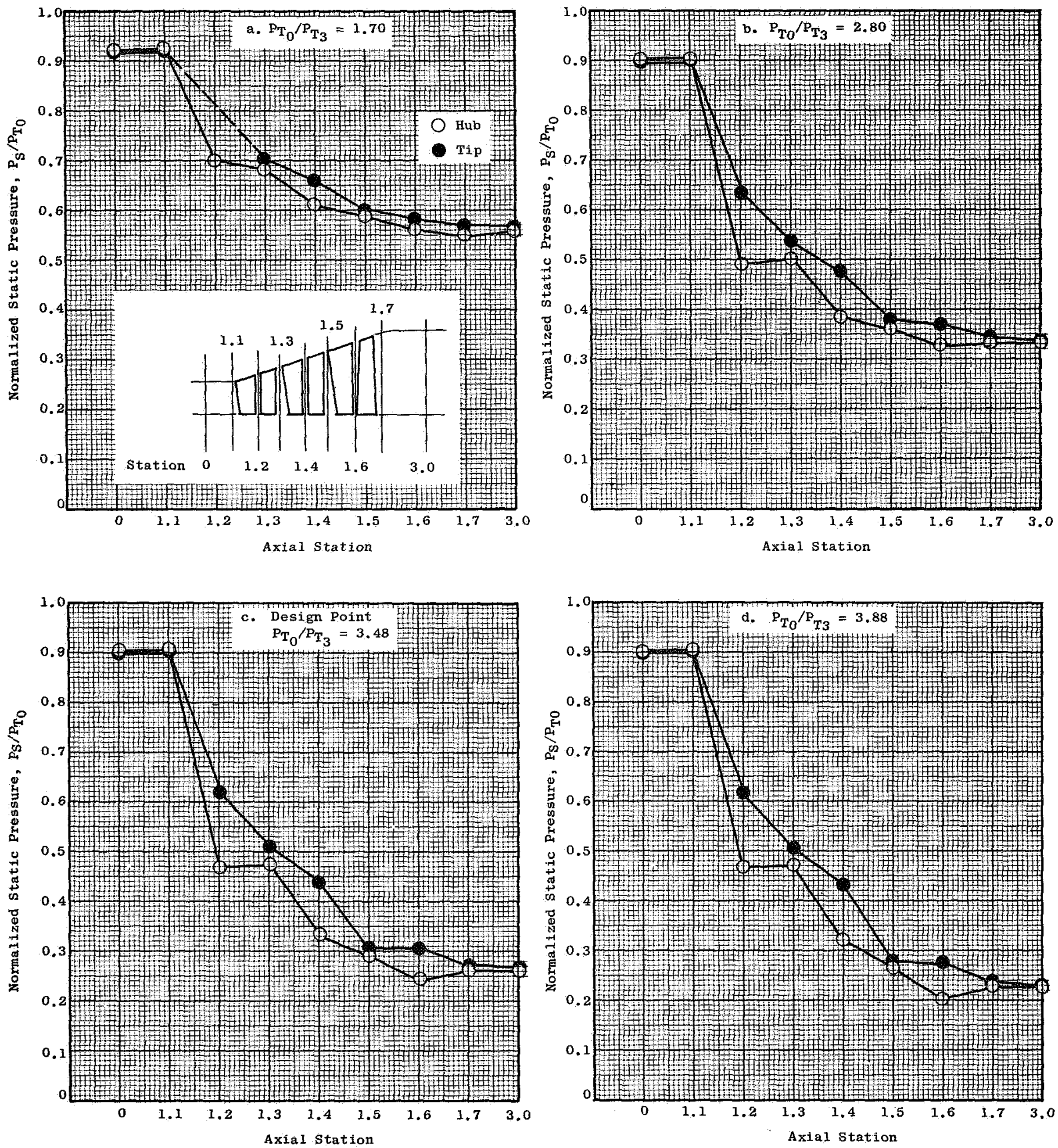


Figure 79. Normalized Static Pressure Vs. Axial Station, Configuration 1 (PPPPPP), at Design Equivalent Speed.

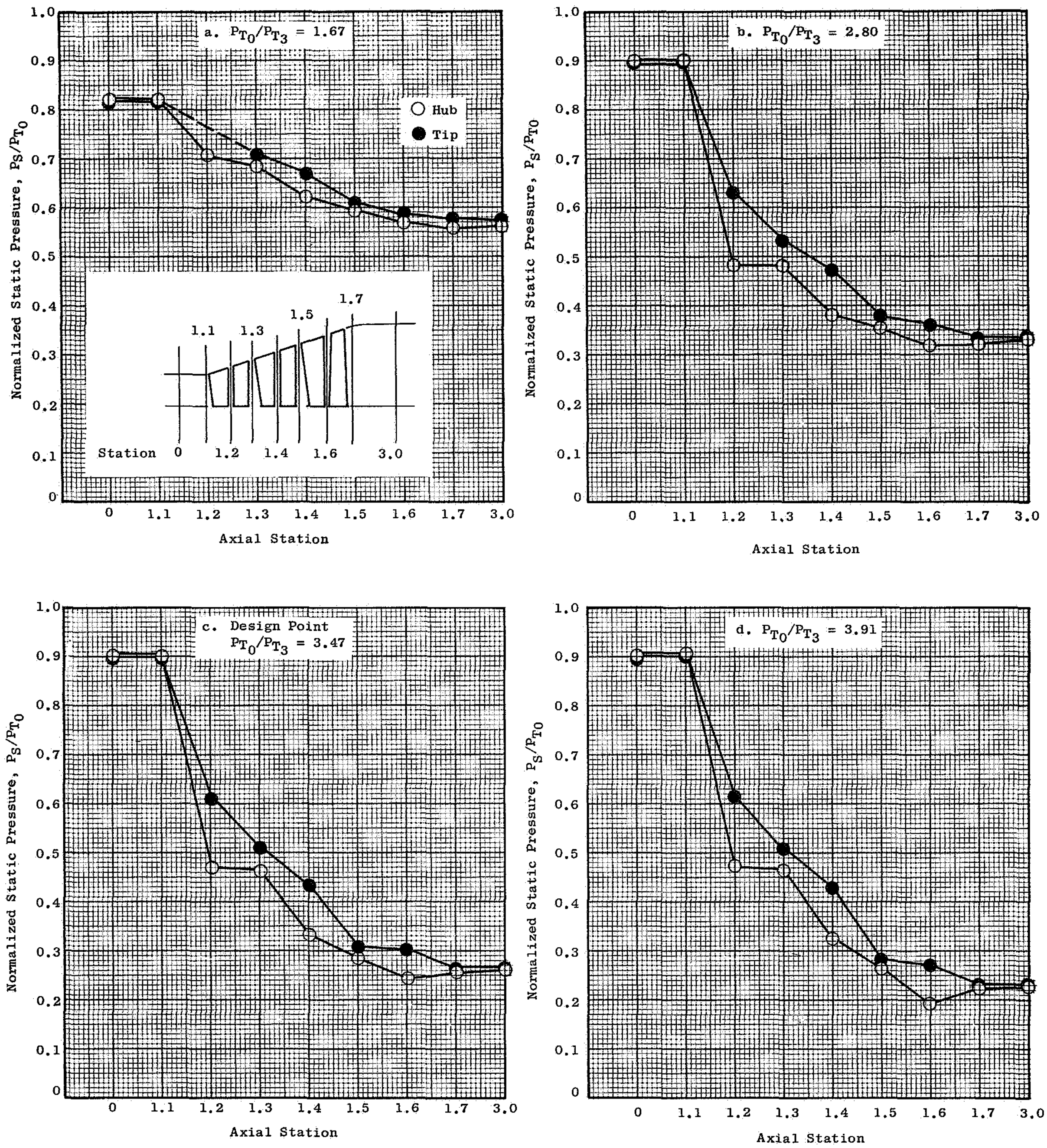


Figure 80. Normalized Static Pressure Vs. Axial Station, Configuration 5 (PPPPPT), at Design Equvalent Speed.

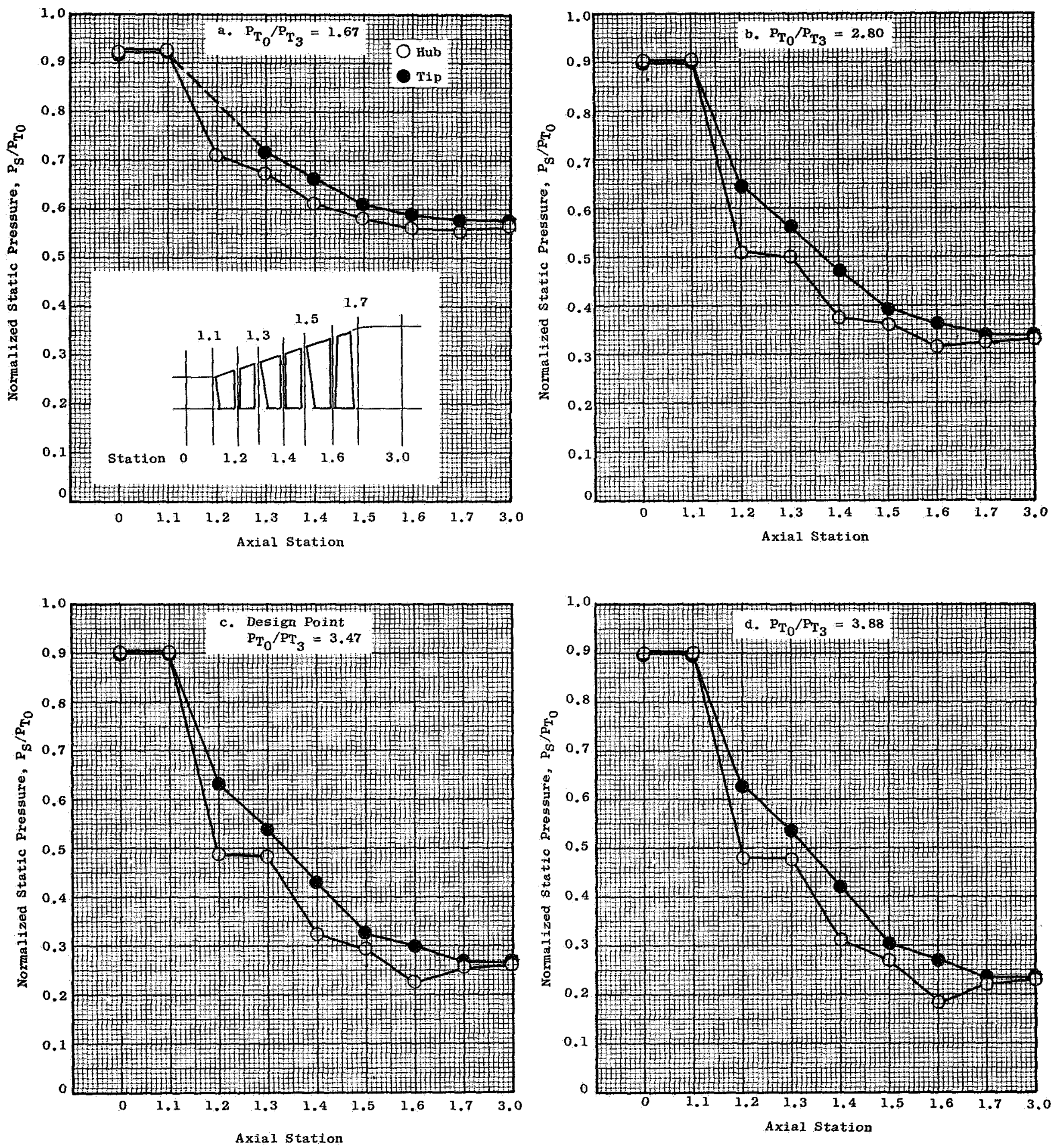


Figure 81. Normalized Static Pressure Vs. Axial Station, Configuration 6 (PPTPTT), at Design Equivalent Speed.

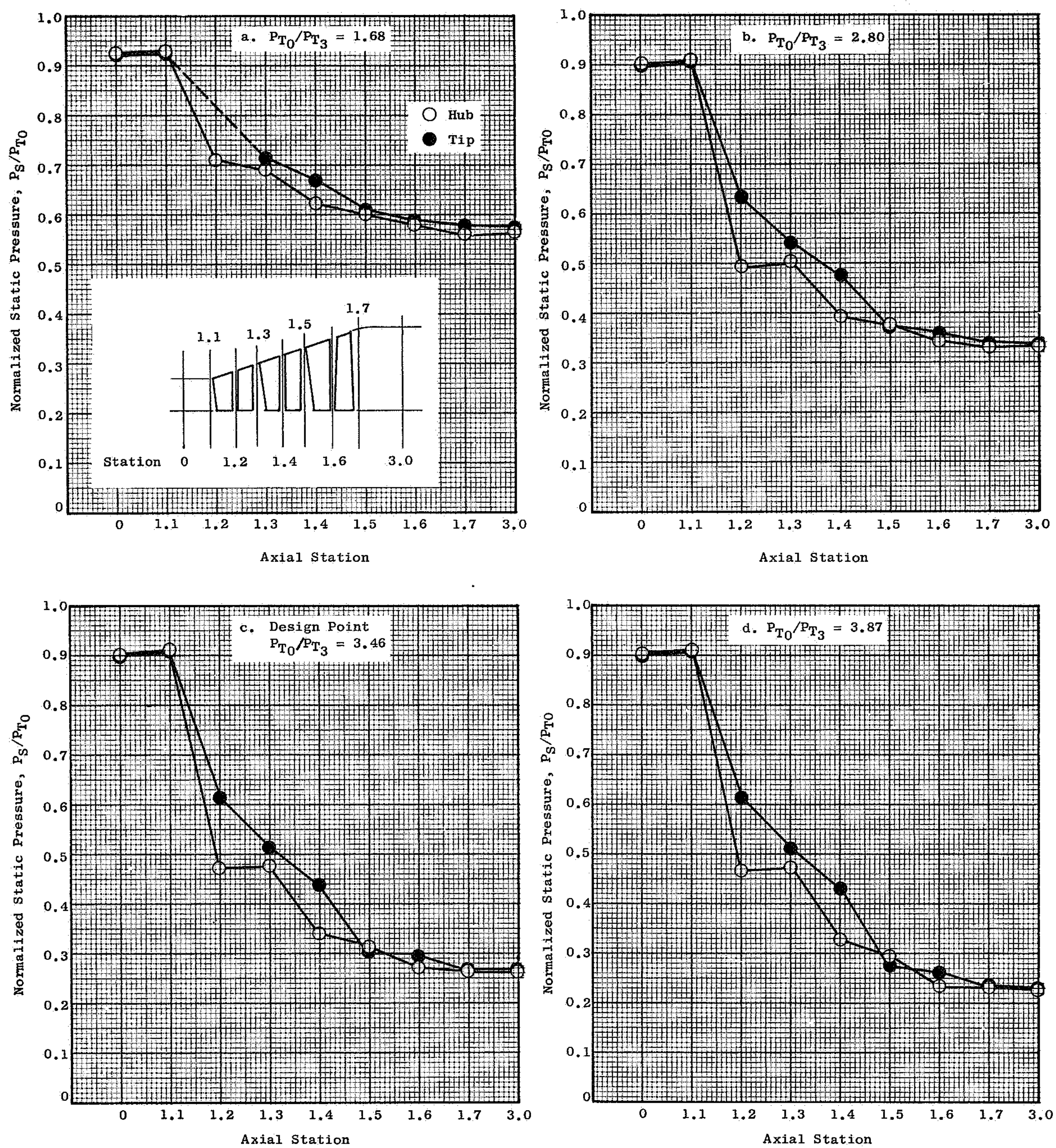


Figure 82. Normalized Static Pressure Vs. Axial Station, Configuration 7 (PPPPLP), at Design Equivalent Speed.

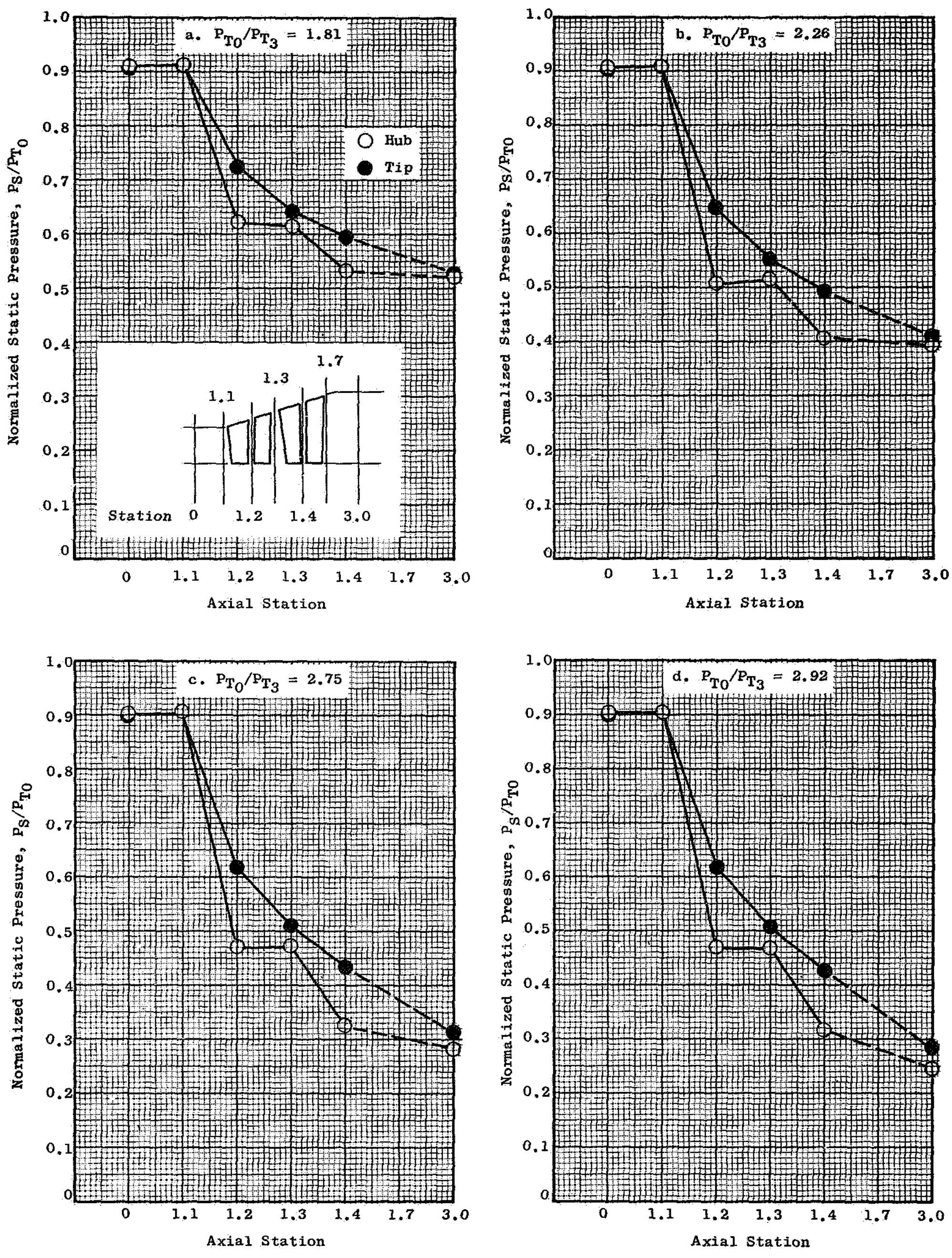


Figure 83. Normalized Static Pressure Vs. Axial Station, Configuration 2 (PPPP), at Design Equvalent Speed.

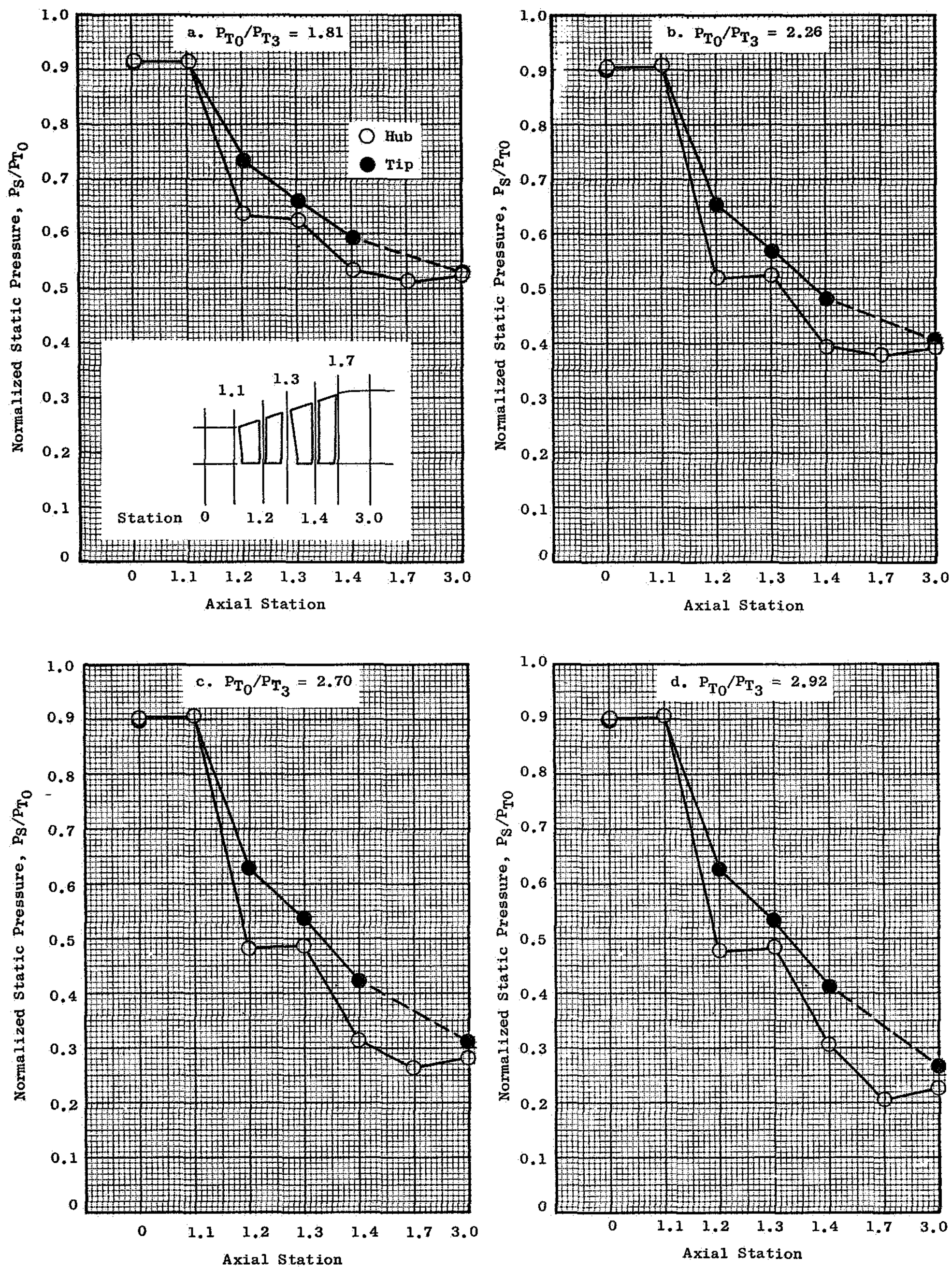


Figure 84. Normalized Static Pressure Vs. Axial Station, Configuration 4 (PPTP), at Design Equivalent Speed.

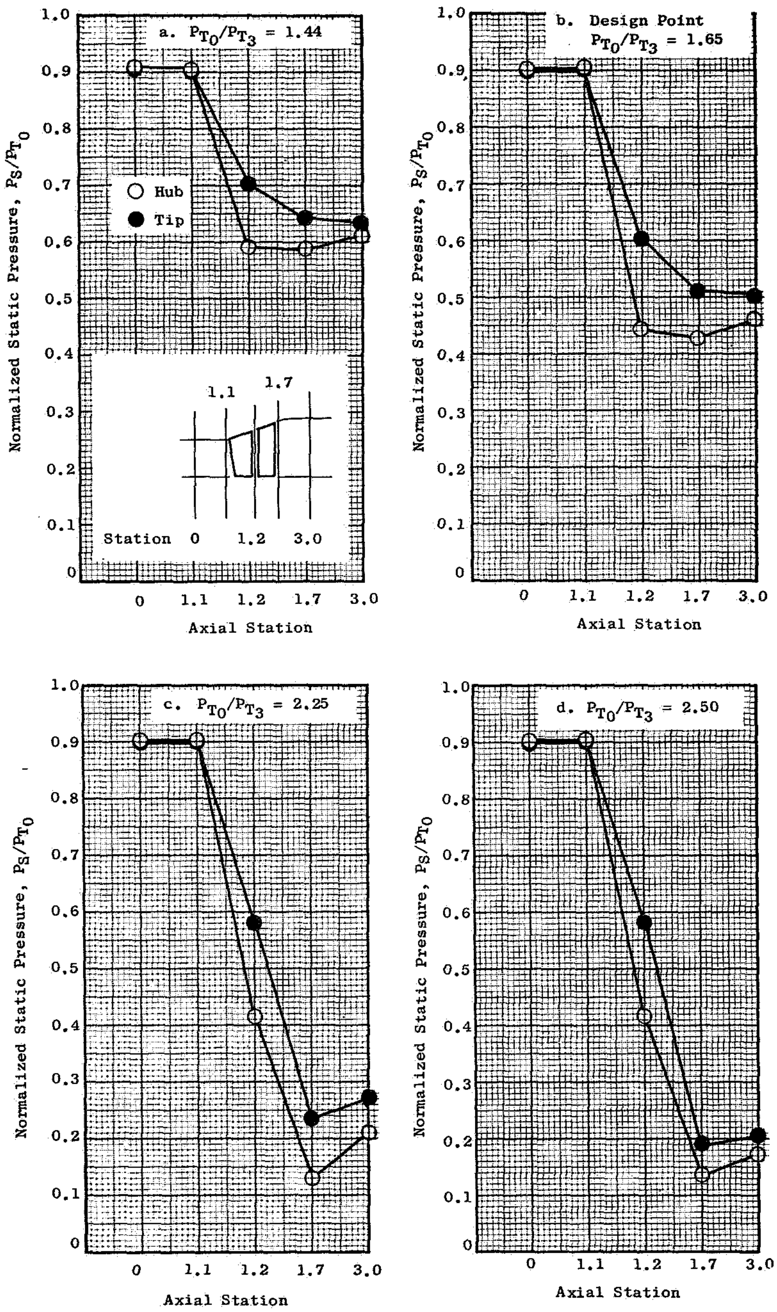


Figure 85. Normalized Static Pressure Vs. Axial Station, Configuration 3 (PP), at Design Equivalent Speed.

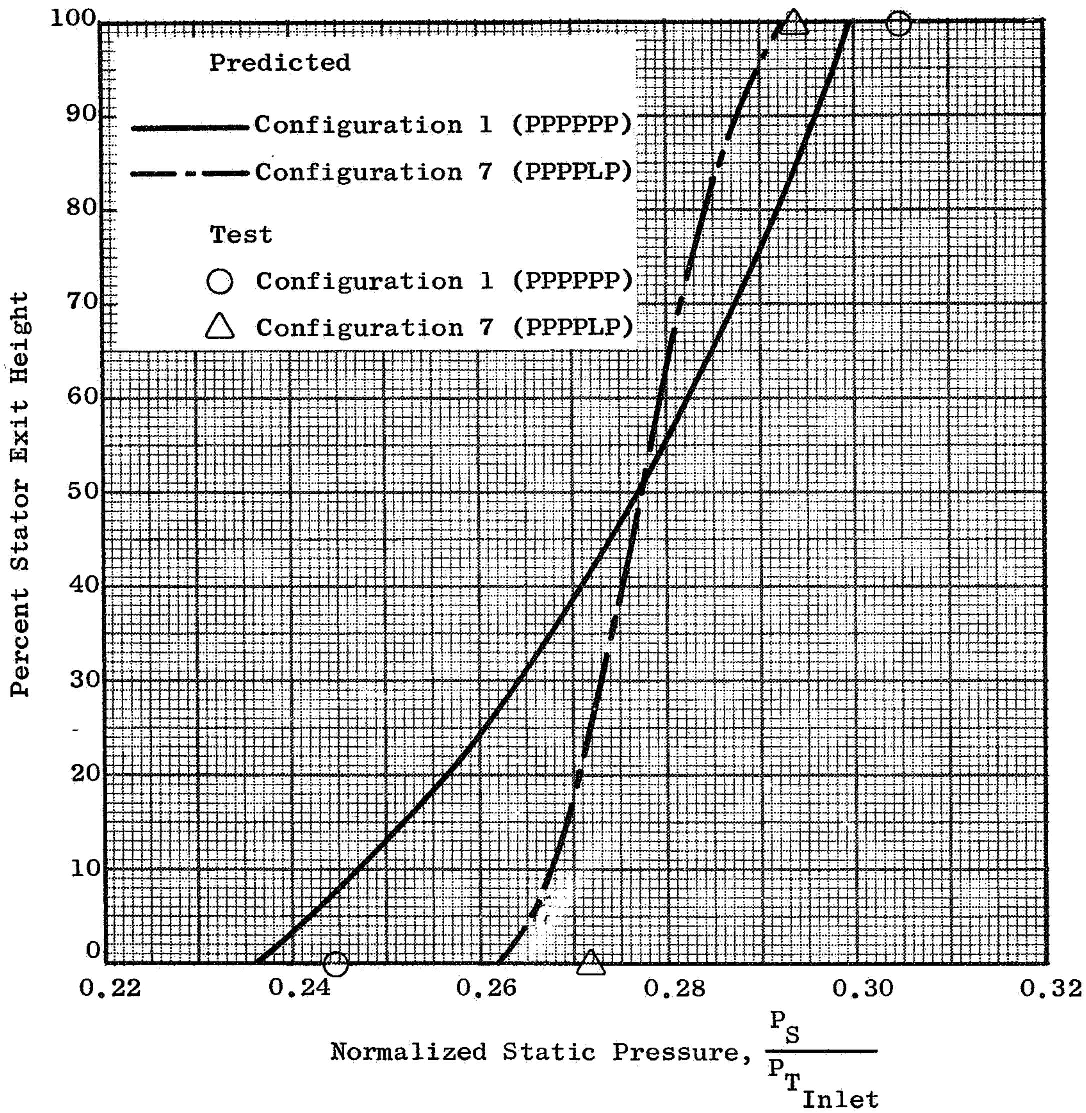


Figure 86. Predicted and Actual Design Point Static Pressure at Stage Three Stator Exit.

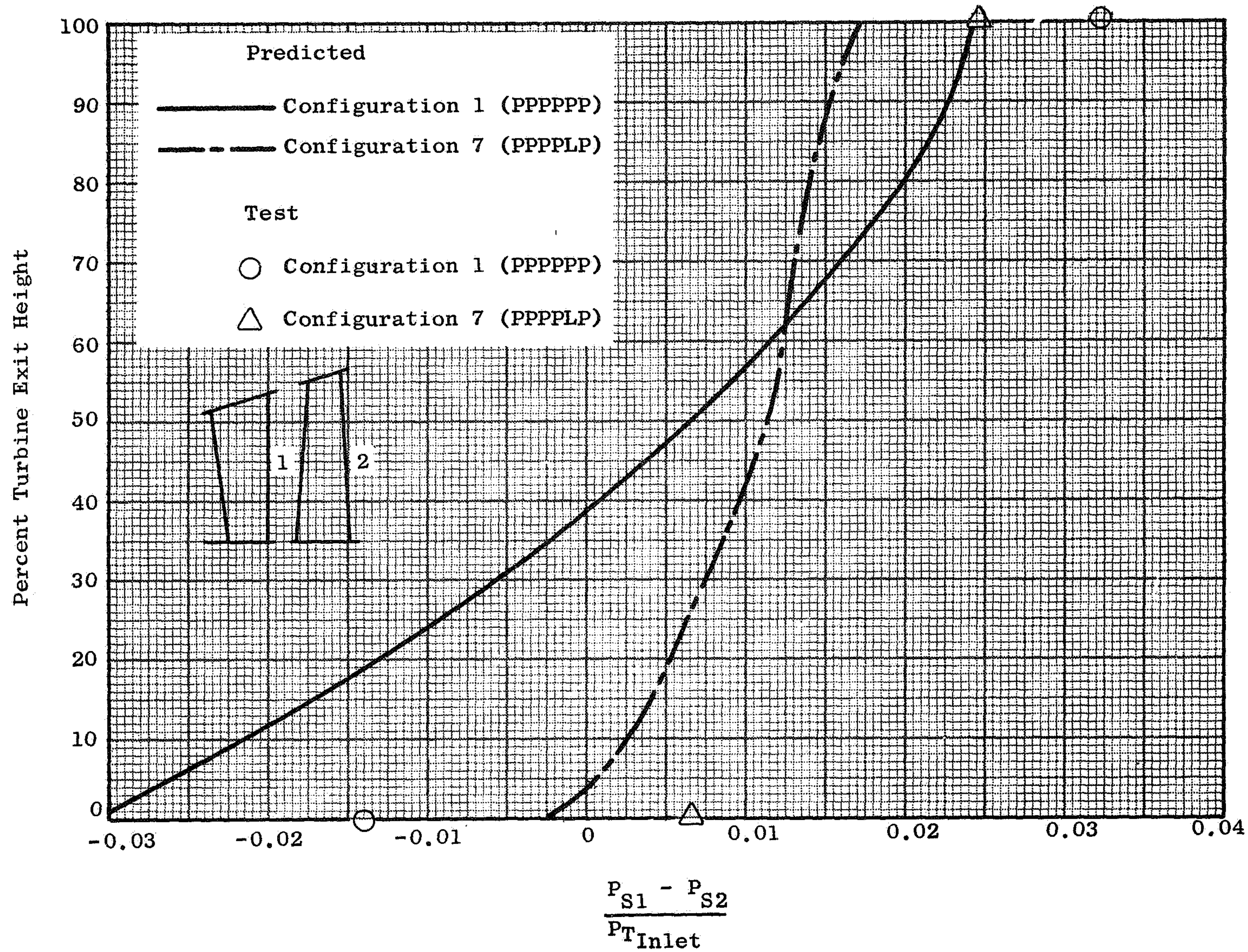


Figure 87. Predicted and Actual Design Point Static Pressure Change Across Stage Three Rotor.

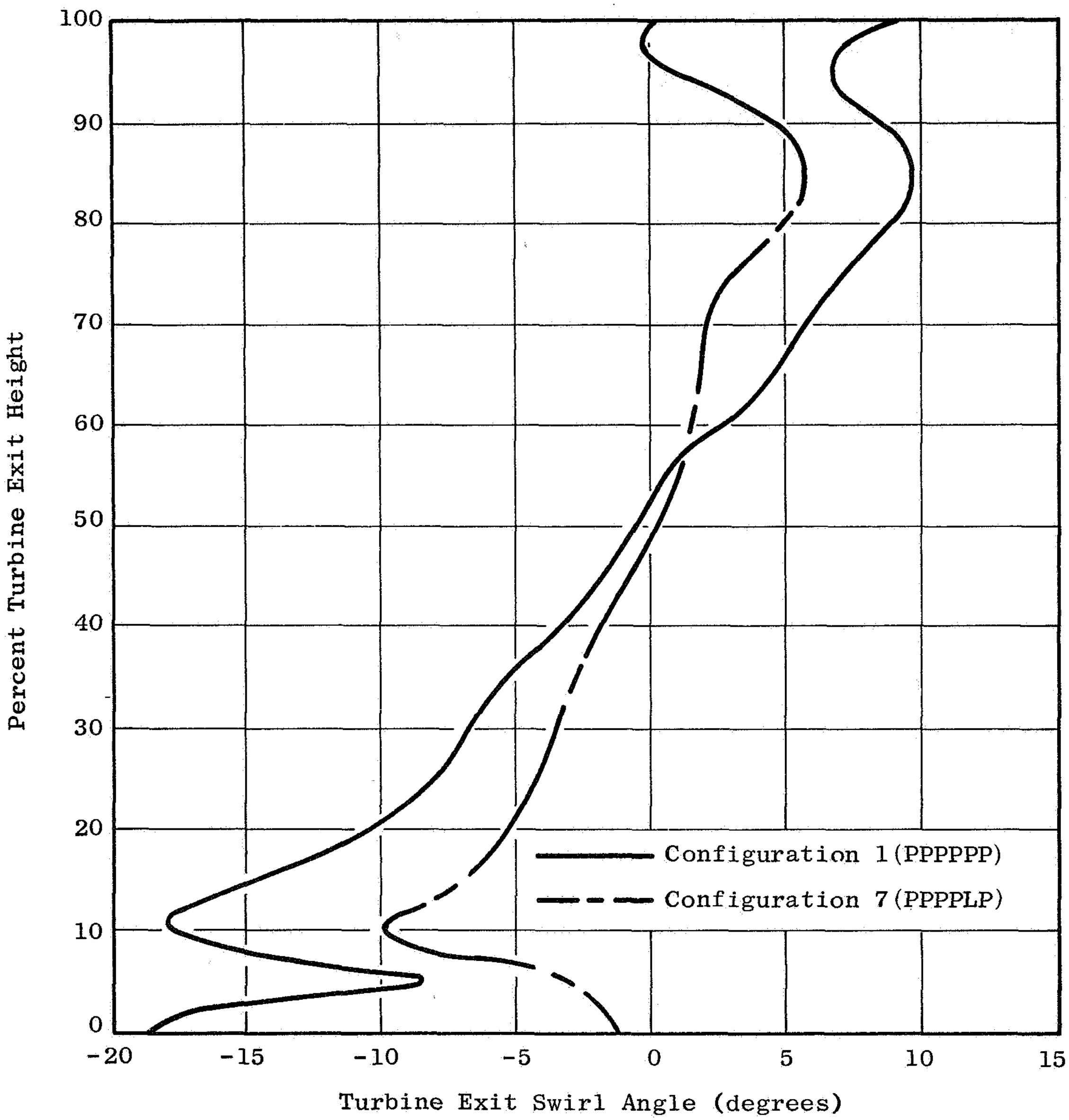


Figure 88. Radial Variation in Design Point Turbine Exit Swirl for Plain Blade and Leaned Stator Turbines.

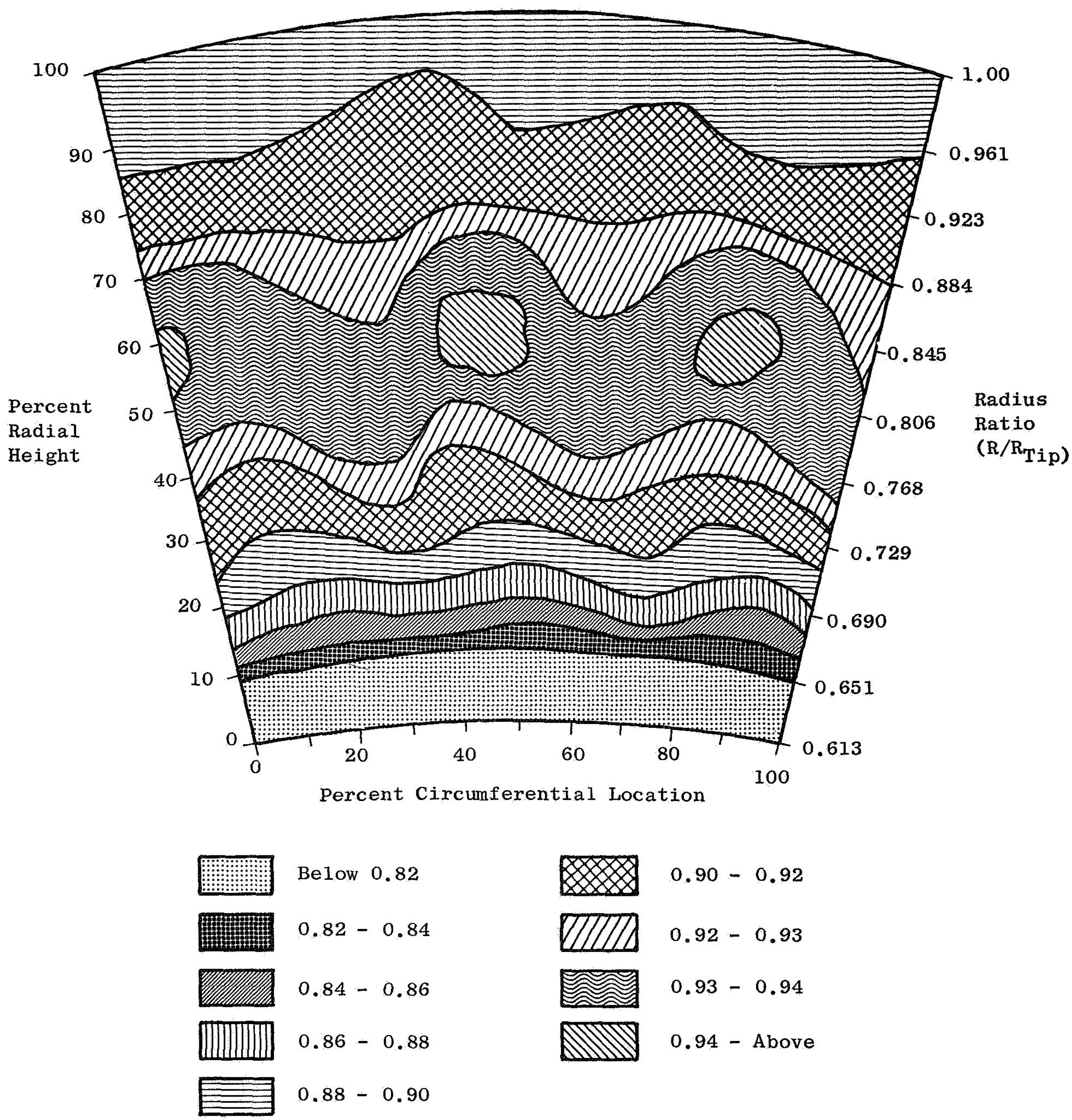


Figure 89. Turbine Efficiency Contour Plot, Configuration 1 (PPPPPP).

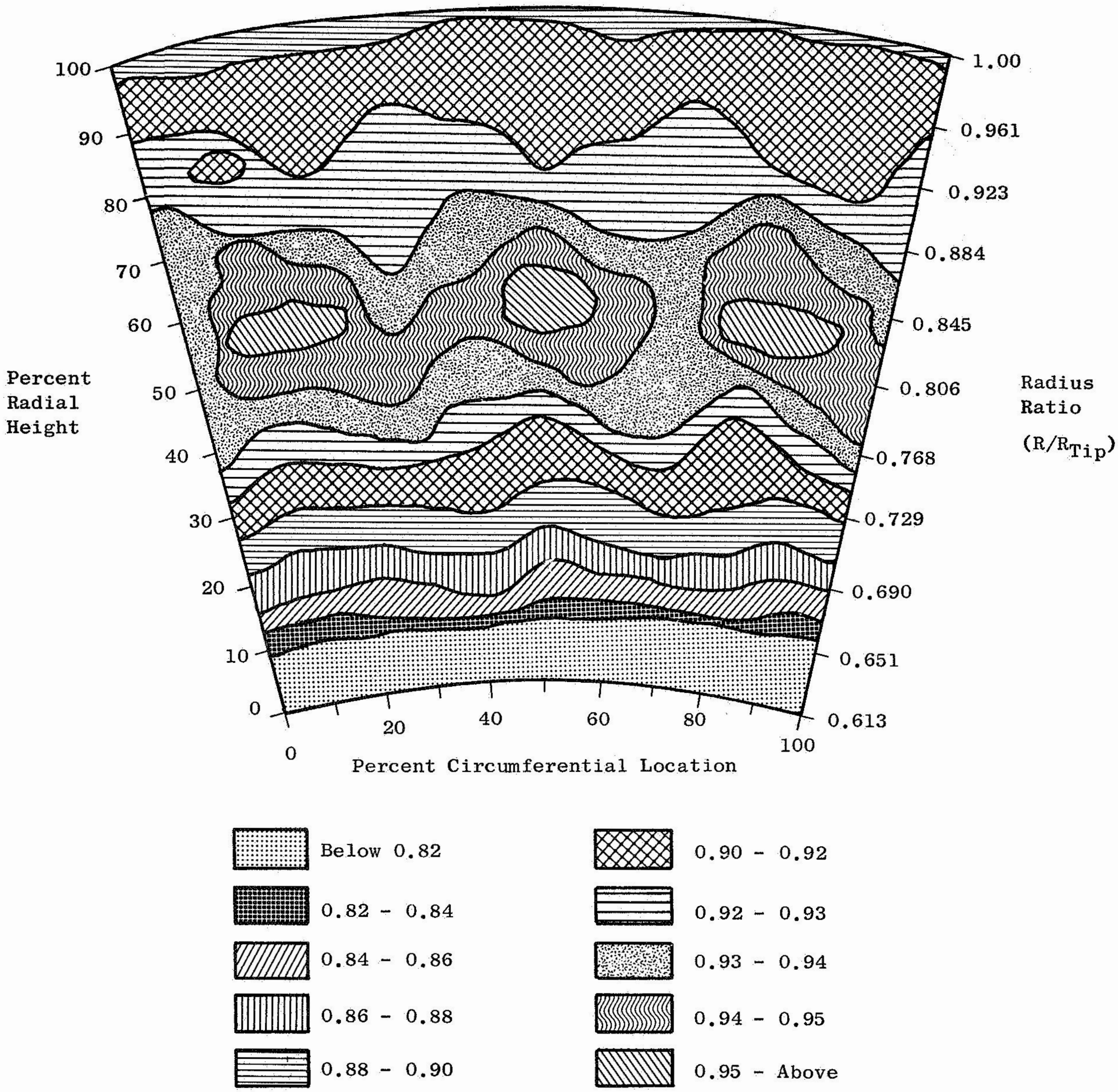


Figure 90. Turbine Efficiency Contour Plot, Configuration 5 (PPPPPT).

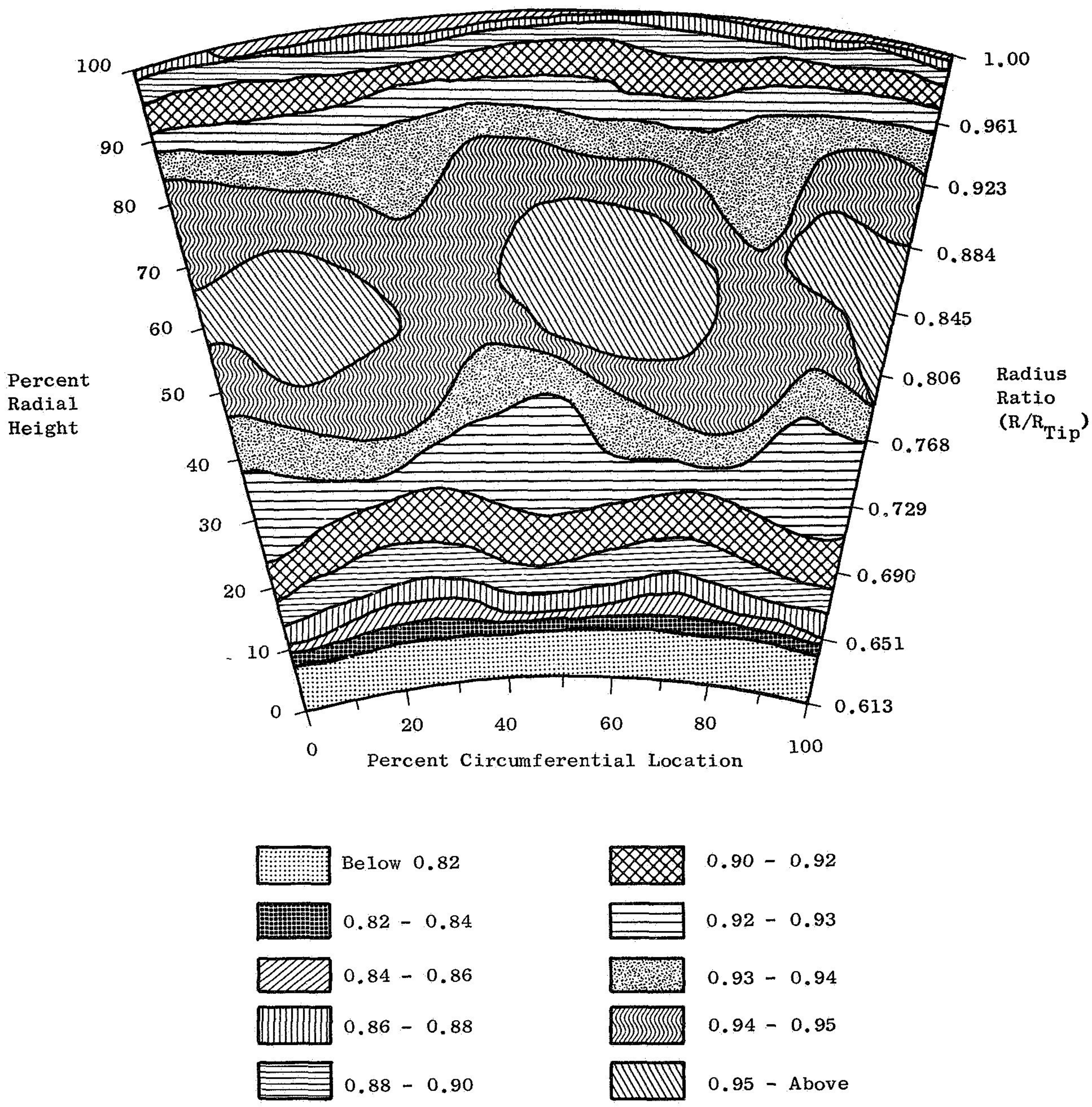


Figure 91. Turbine Efficiency Contour Plot, Configuration 6 (PPTPTT).

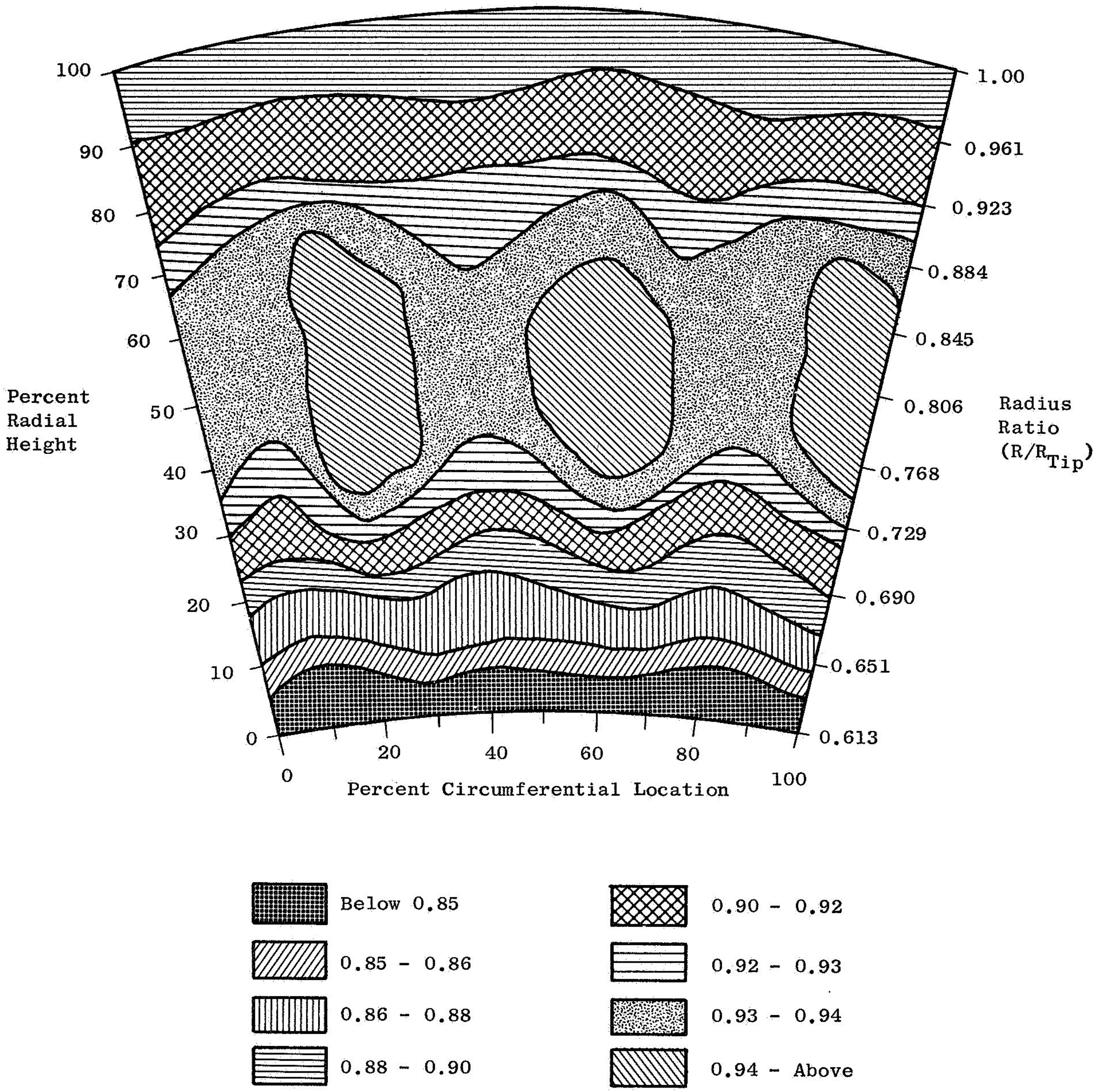


Figure 92. Turbine Efficiency Contour Plot, Configuration 7 (PPPPLP).

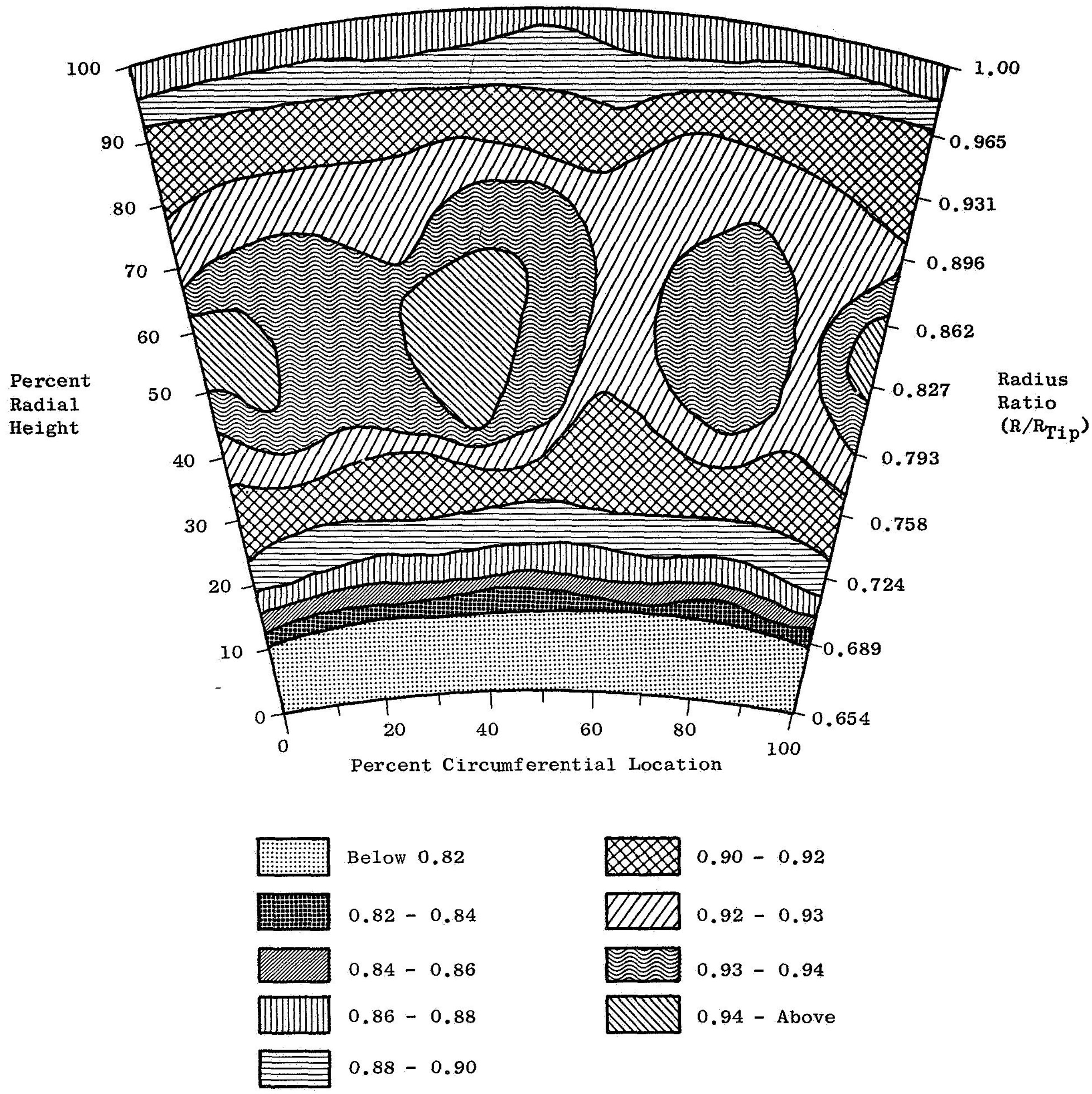


Figure 93. Turbine Efficiency Contour Plot, Configuration 2 (PPPP).

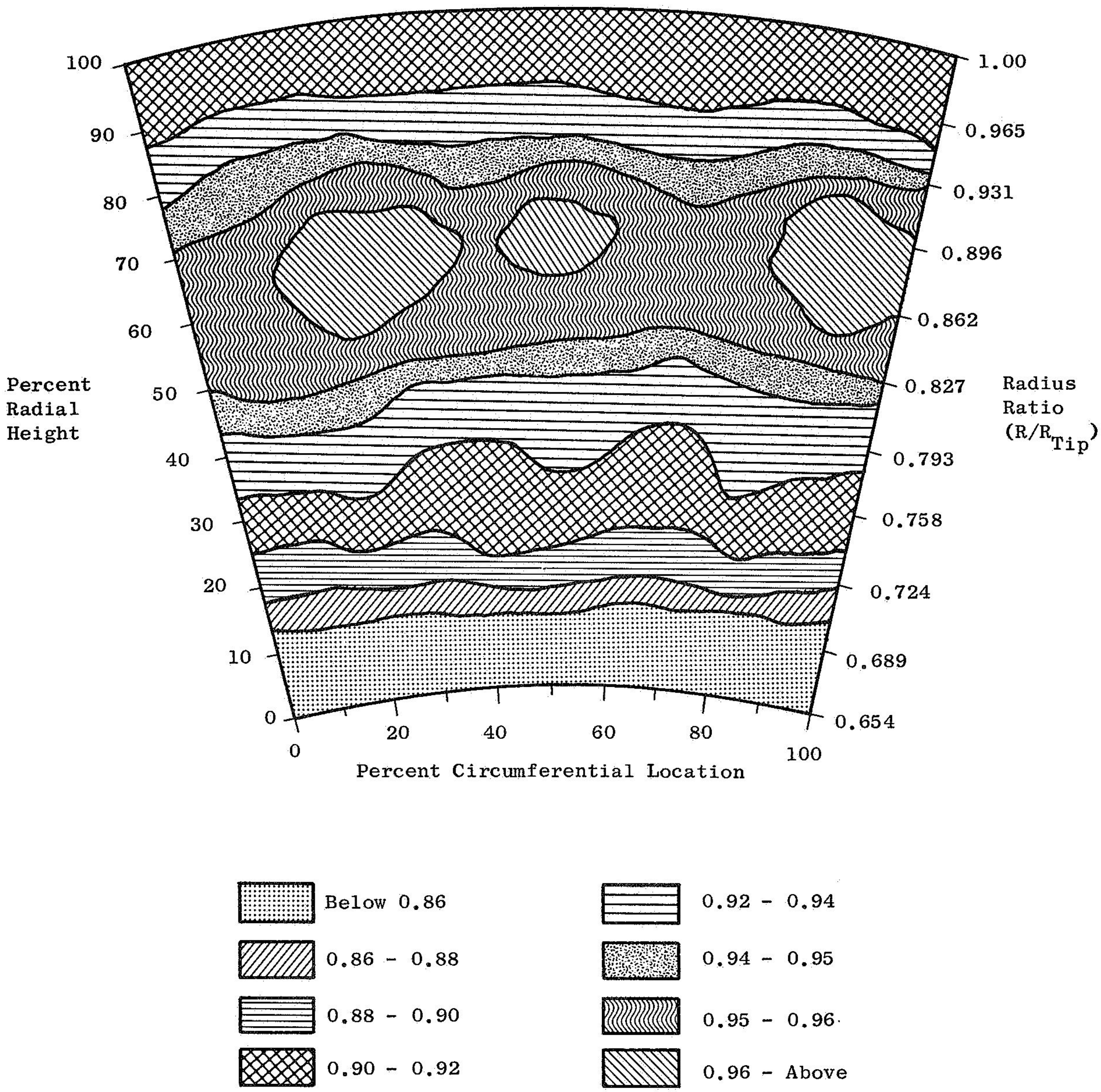


Figure 94. Turbine Efficiency Contour Plot, Configuration 4 (PPTP).

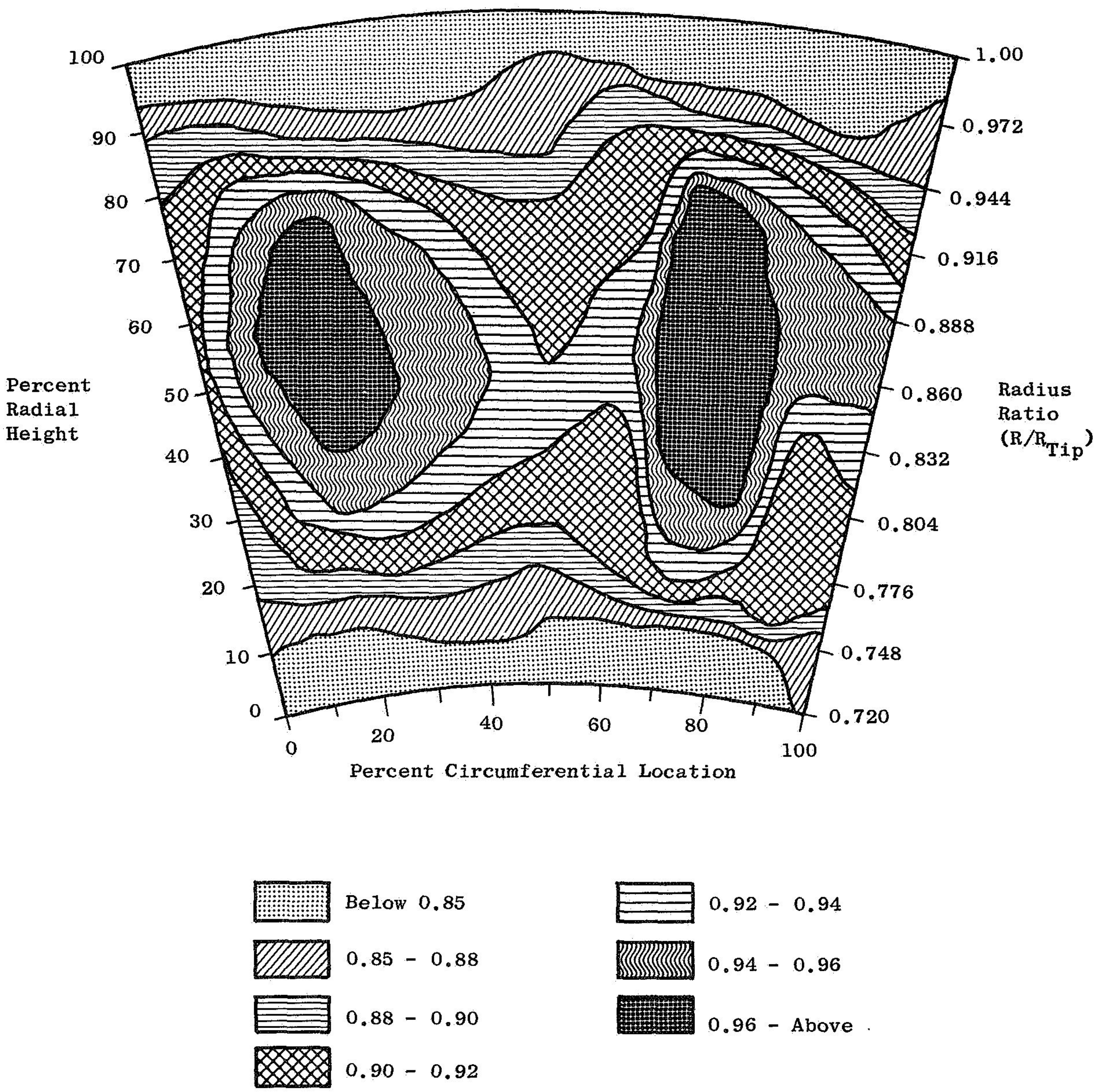


Figure 95. Turbine Efficiency Contour Plot, Configuration 3 (PP).

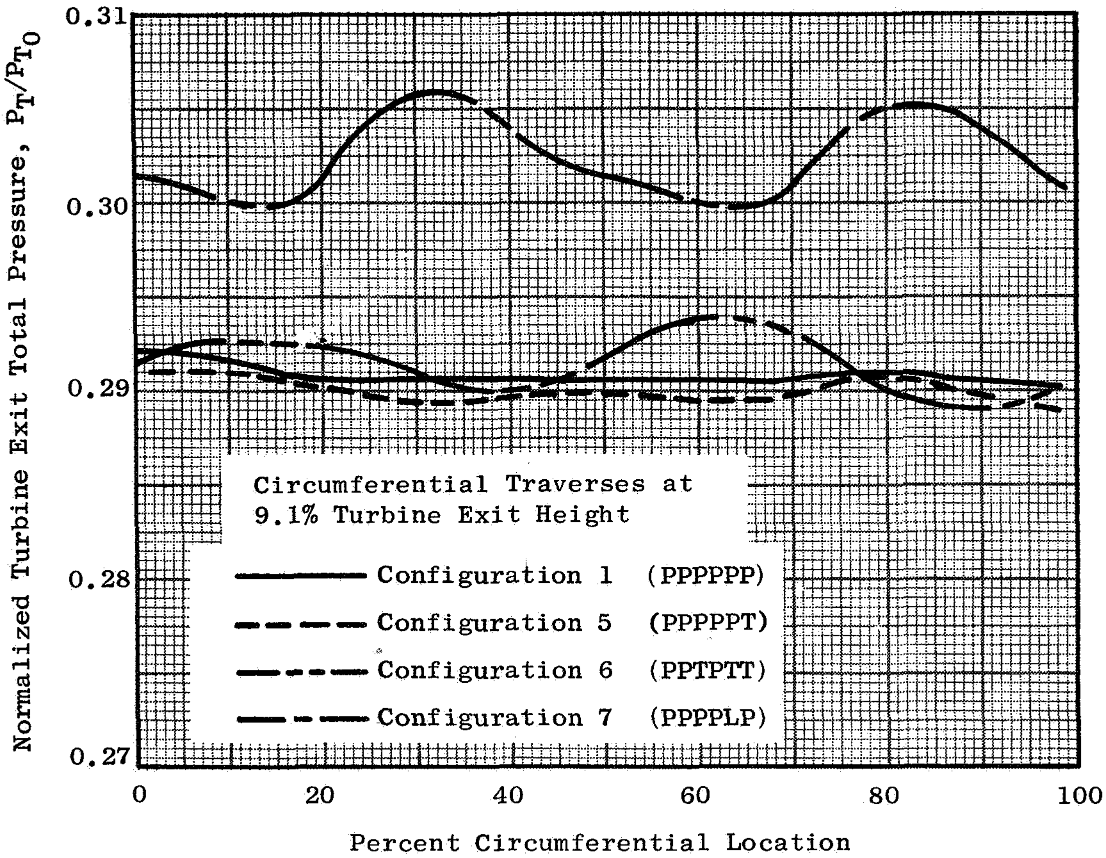


Figure 96. Hub Region Total-to-Total Pressure Ratio Vs. Circumferential Location, Three-Stage Turbines.

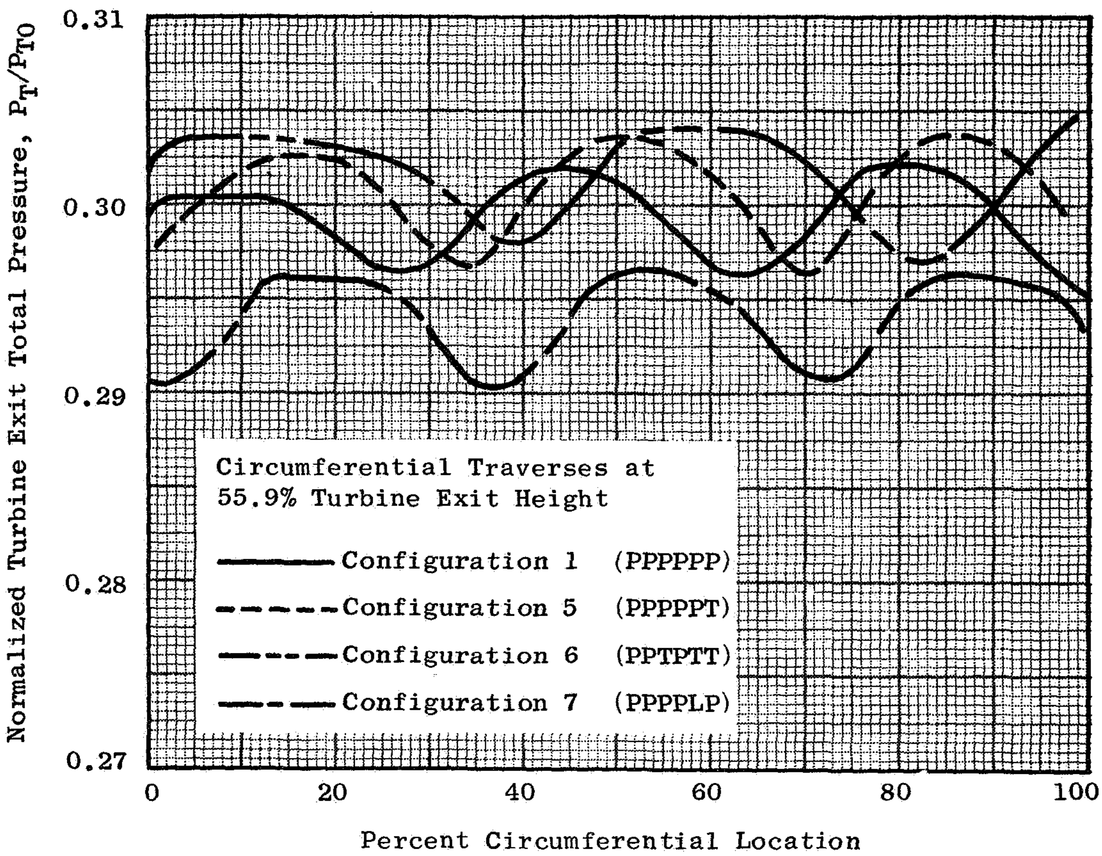


Figure 97. Pitch Region Total-to-Total Pressure Ratio Vs. Circumferential Location, Three-Stage Turbines.

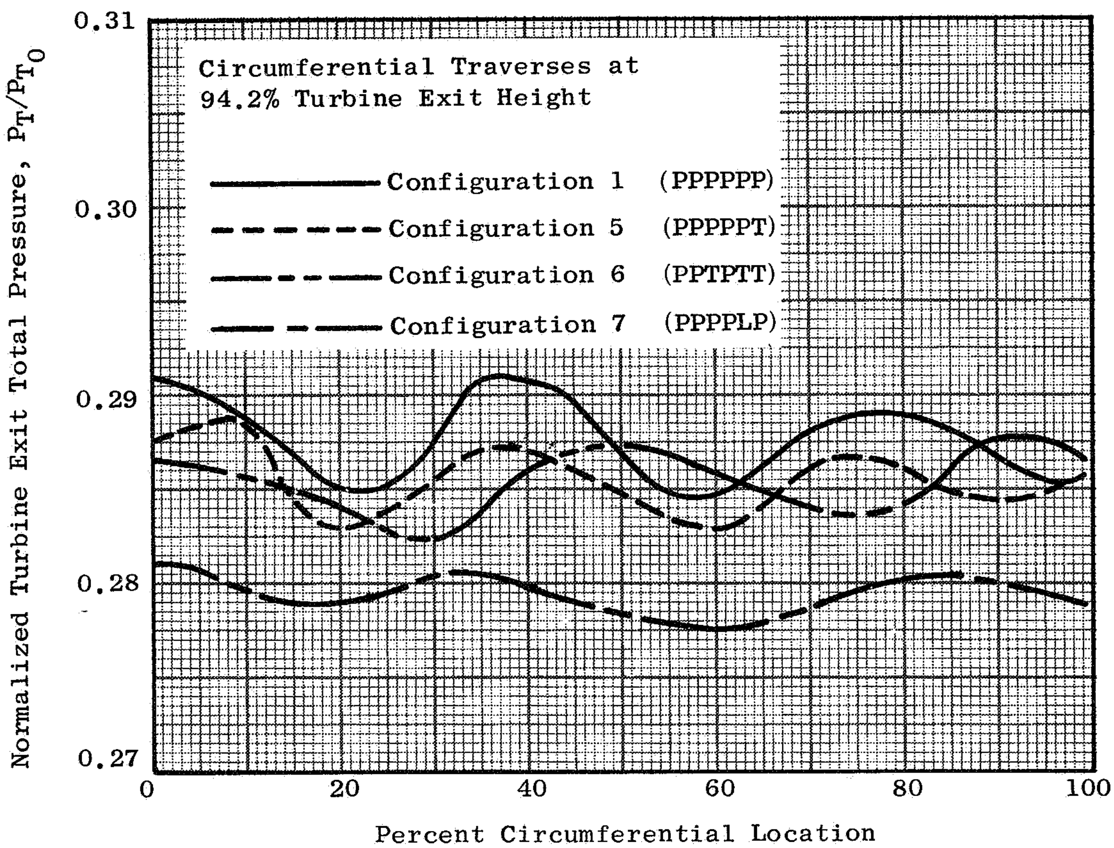


Figure 98. Tip Region Total-to-Total Pressure Ratio Vs. Circumferential Location, Three-Stage Turbines.

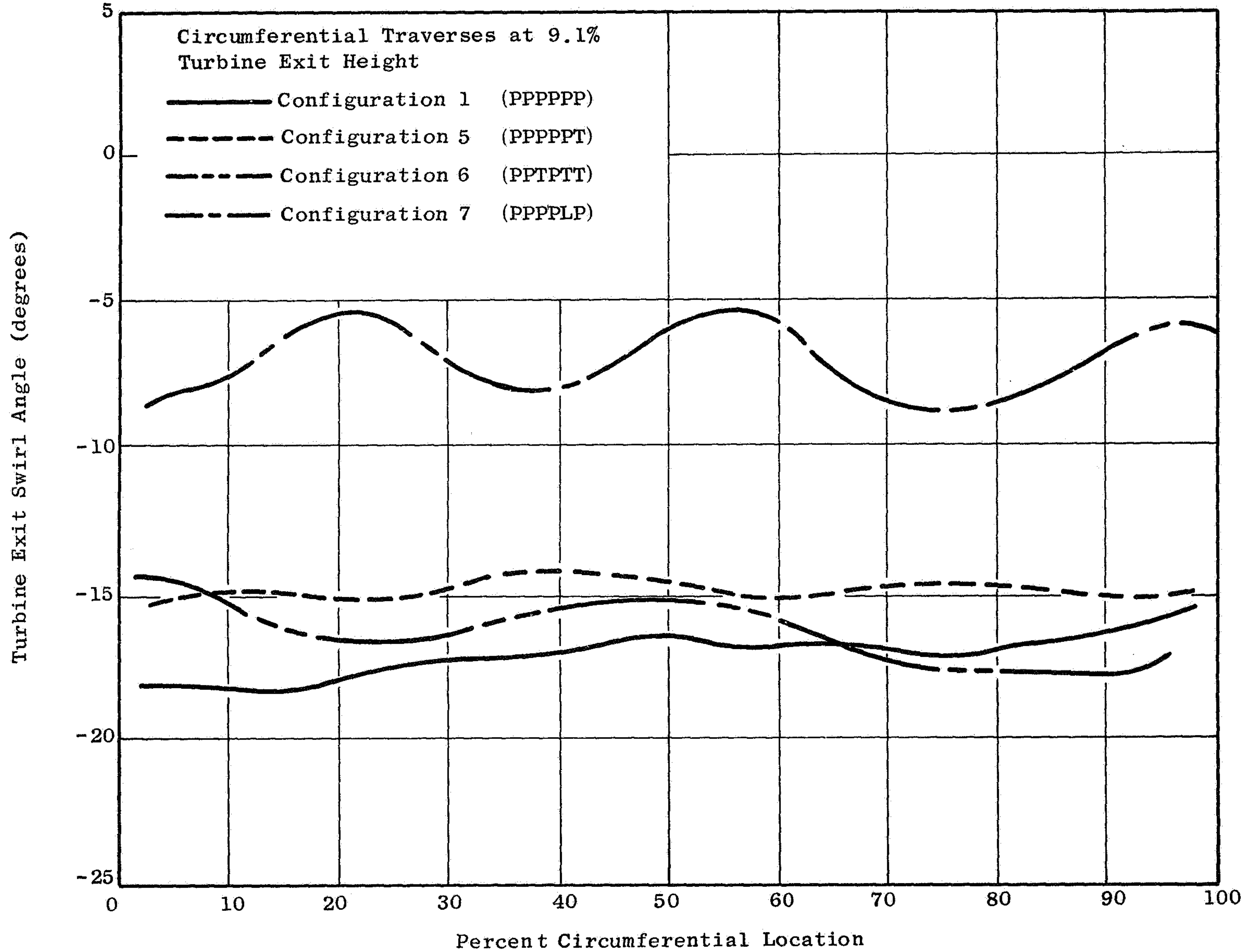


Figure 99. Hub Region Swirl Angle Vs. Circumferential Location, Three-Stage Turbines.

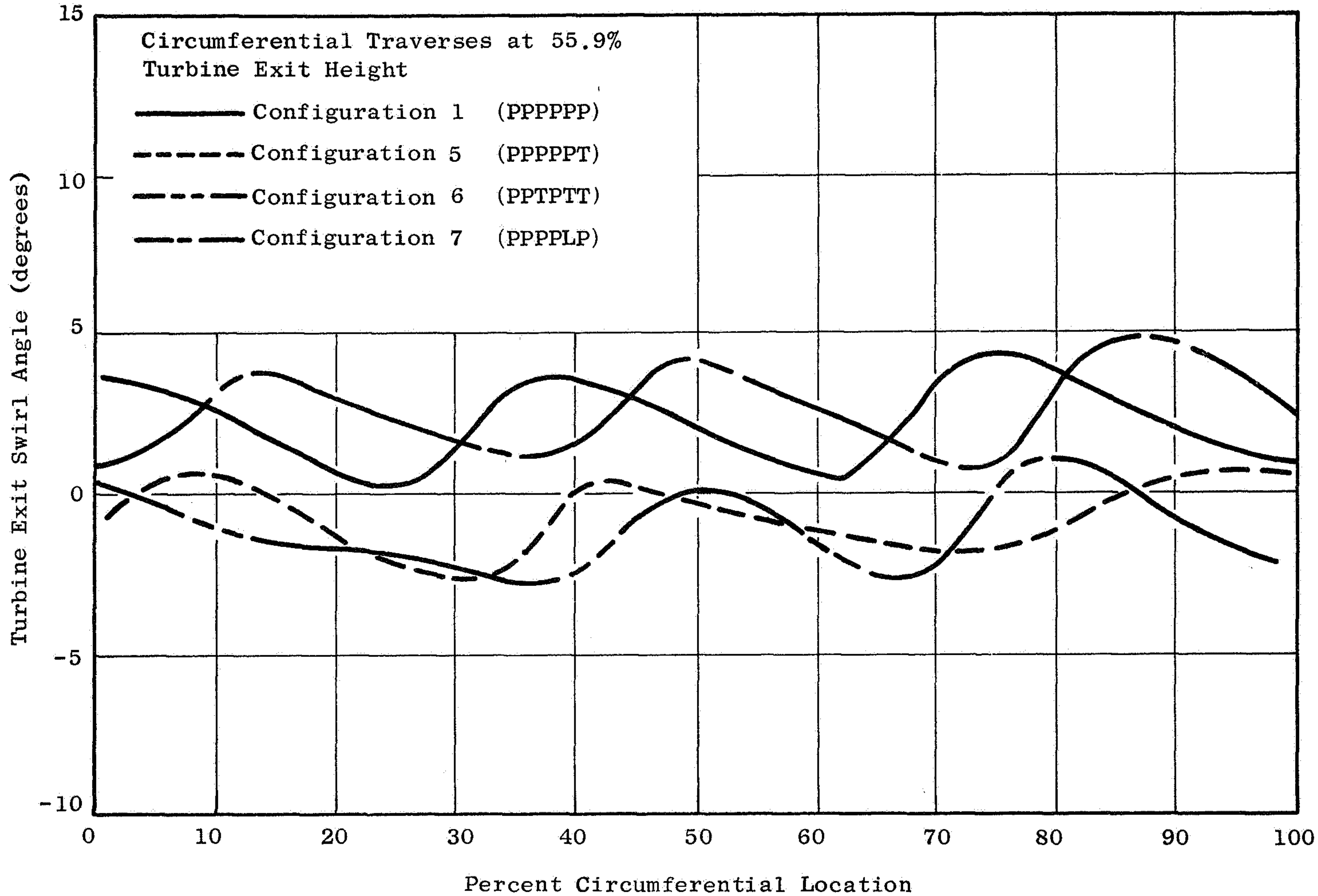


Figure 100. Pitch Region Swirl Angle Vs. Circumferential Location, Three-Stage Turbines.

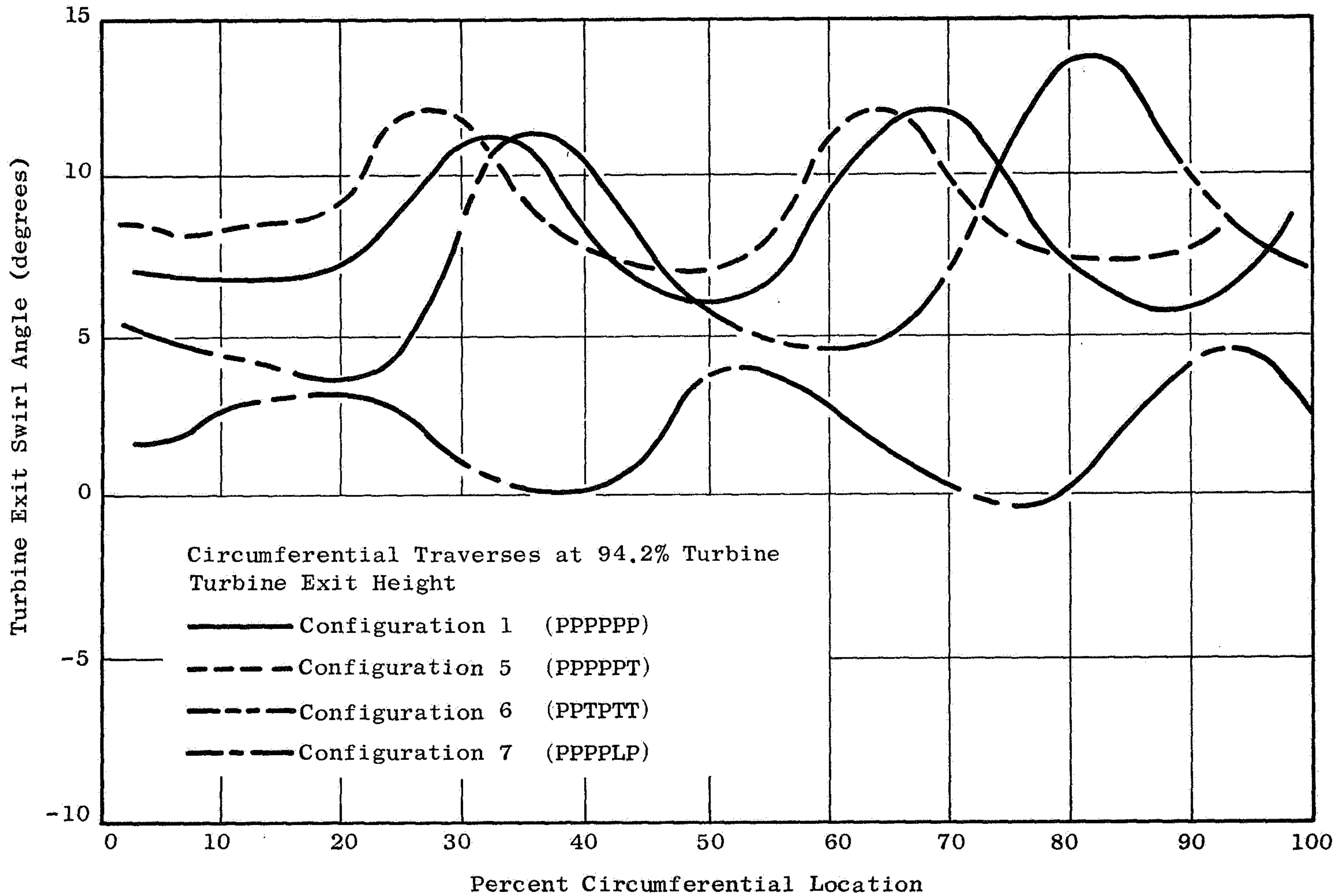


Figure 101. Tip Region Swirl Angle Vs. Circumferential Location, Three-Stage Turbines.

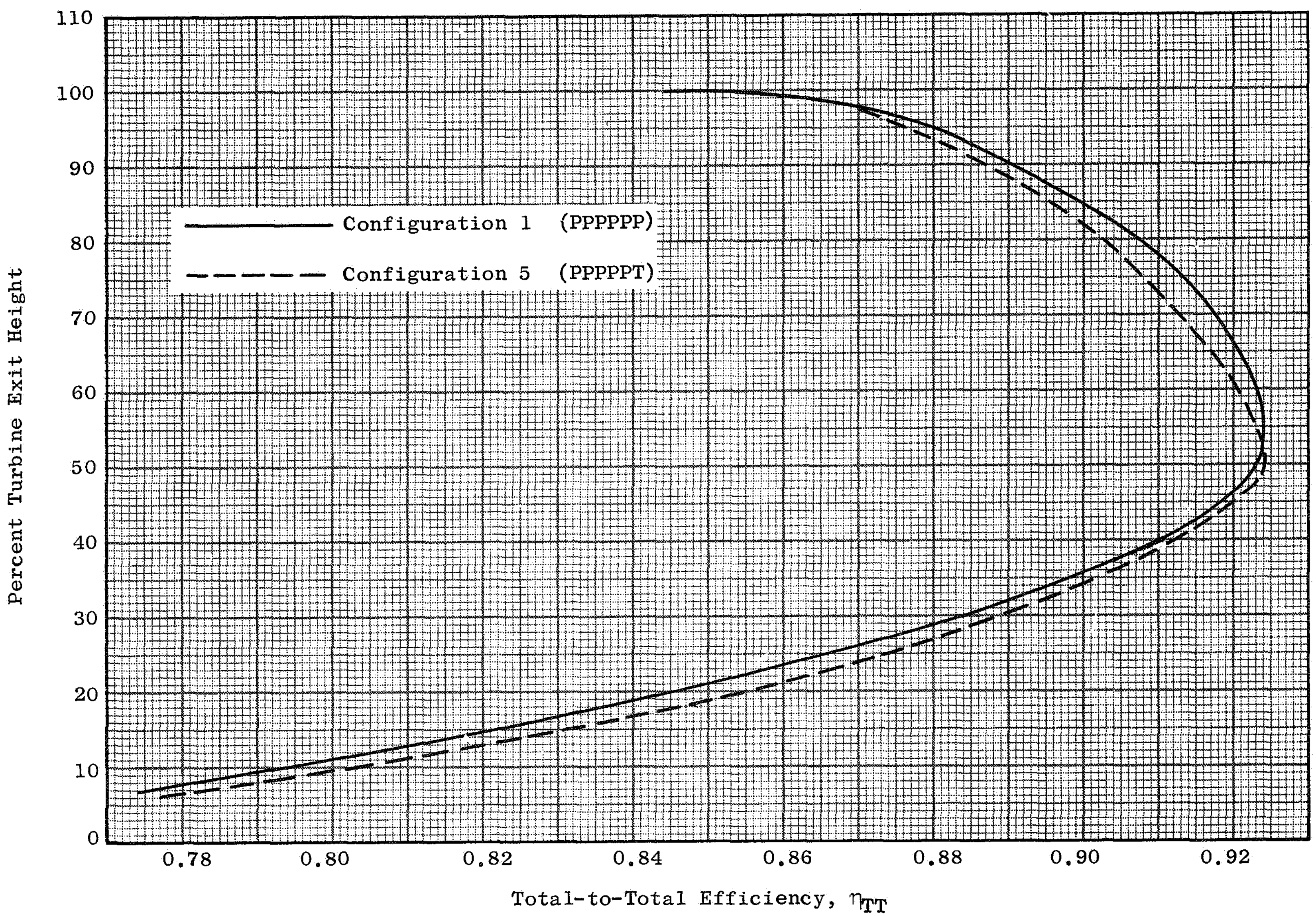


Figure 102. Radial Efficiency Profile, Configuration 5 (PPPPPT) Compared with Configuration 1 (PPPPPP).

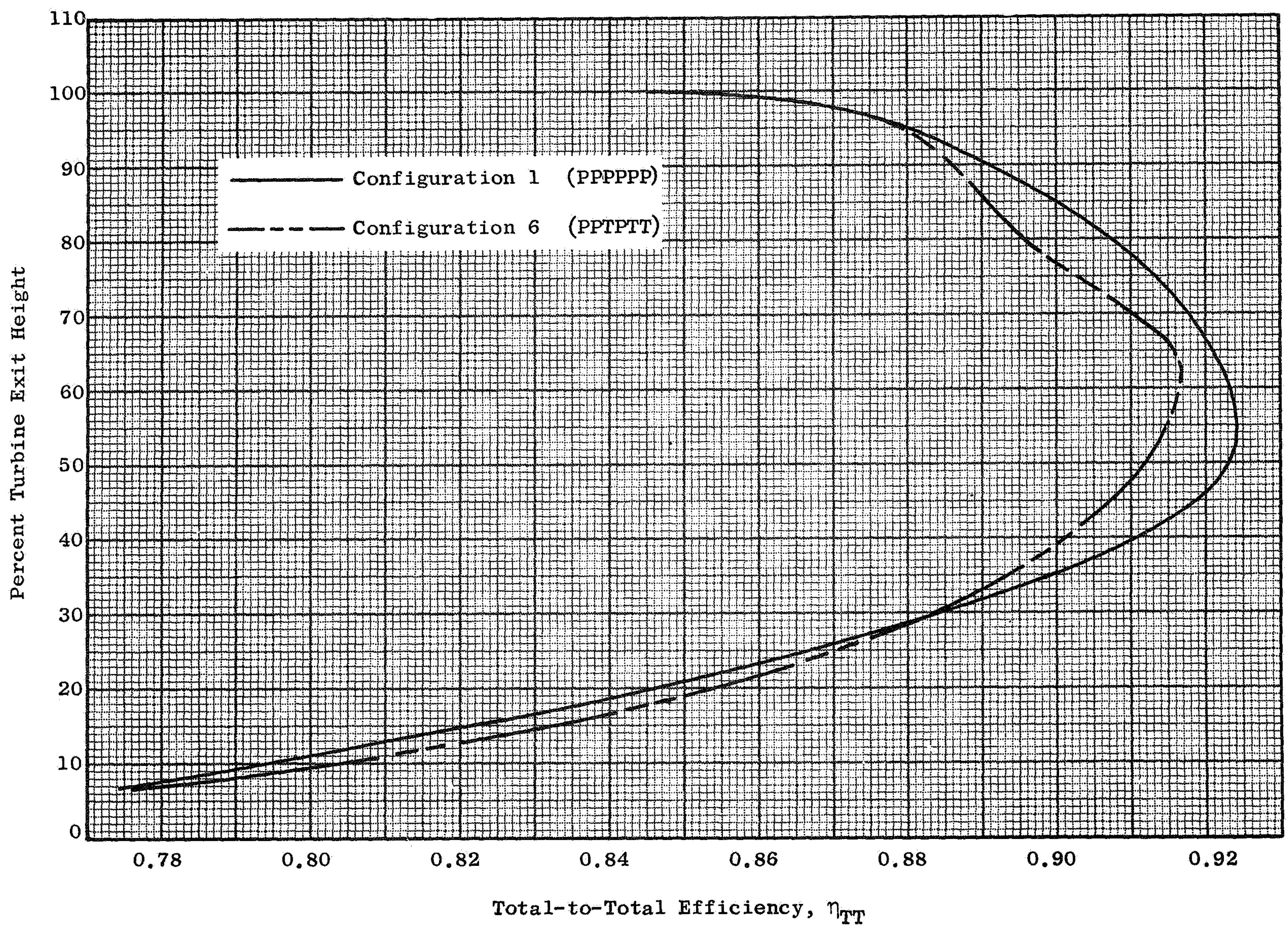


Figure 103. Radial Efficiency Profile, Configuration 6 (PPTPTT) Compared with Configuration 1 (PPPPPP).

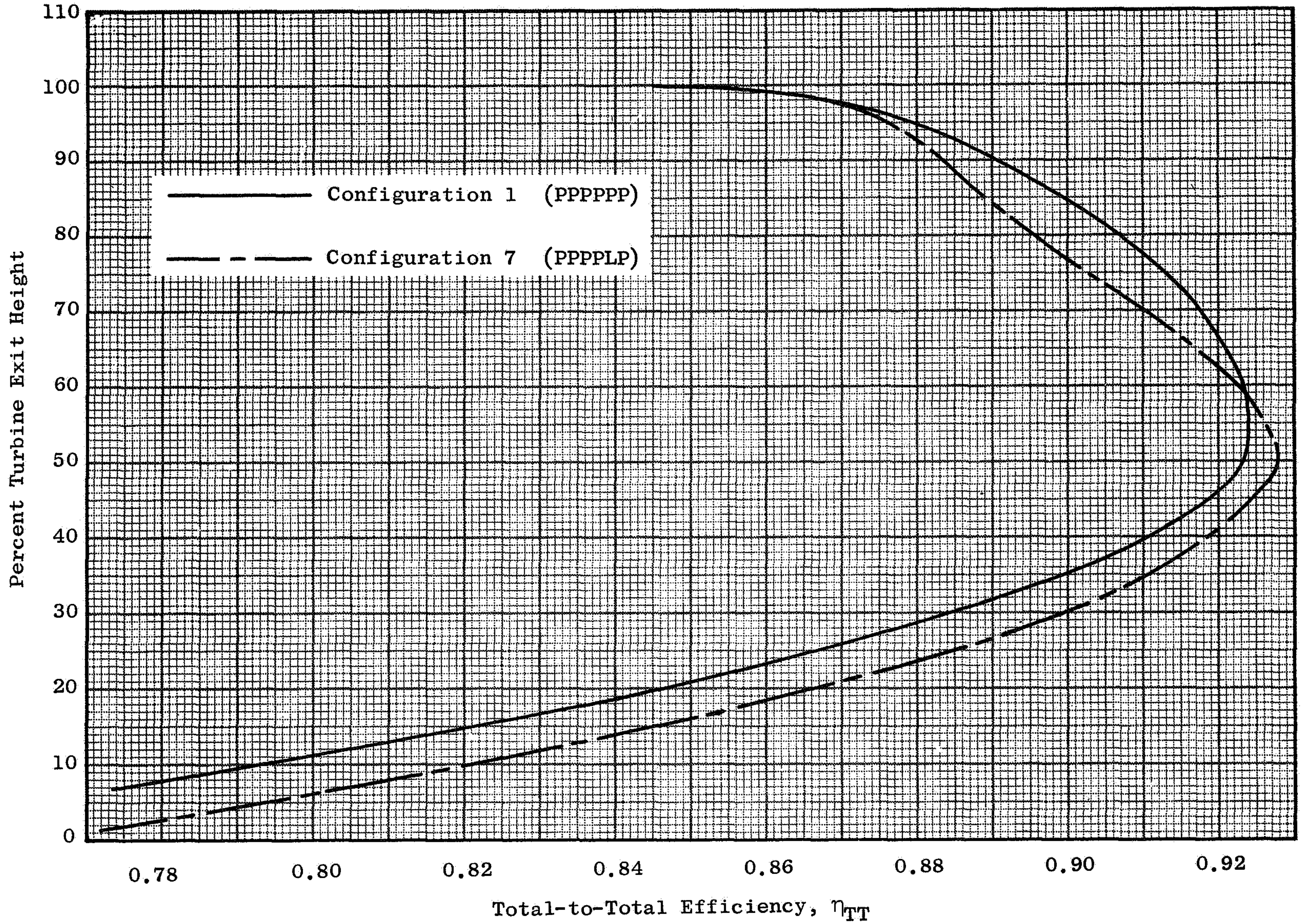


Figure 104. Radial Efficiency Profile, Configuration 7 (PPPPLP) Compared with Configuration 1 (PPPPPP).

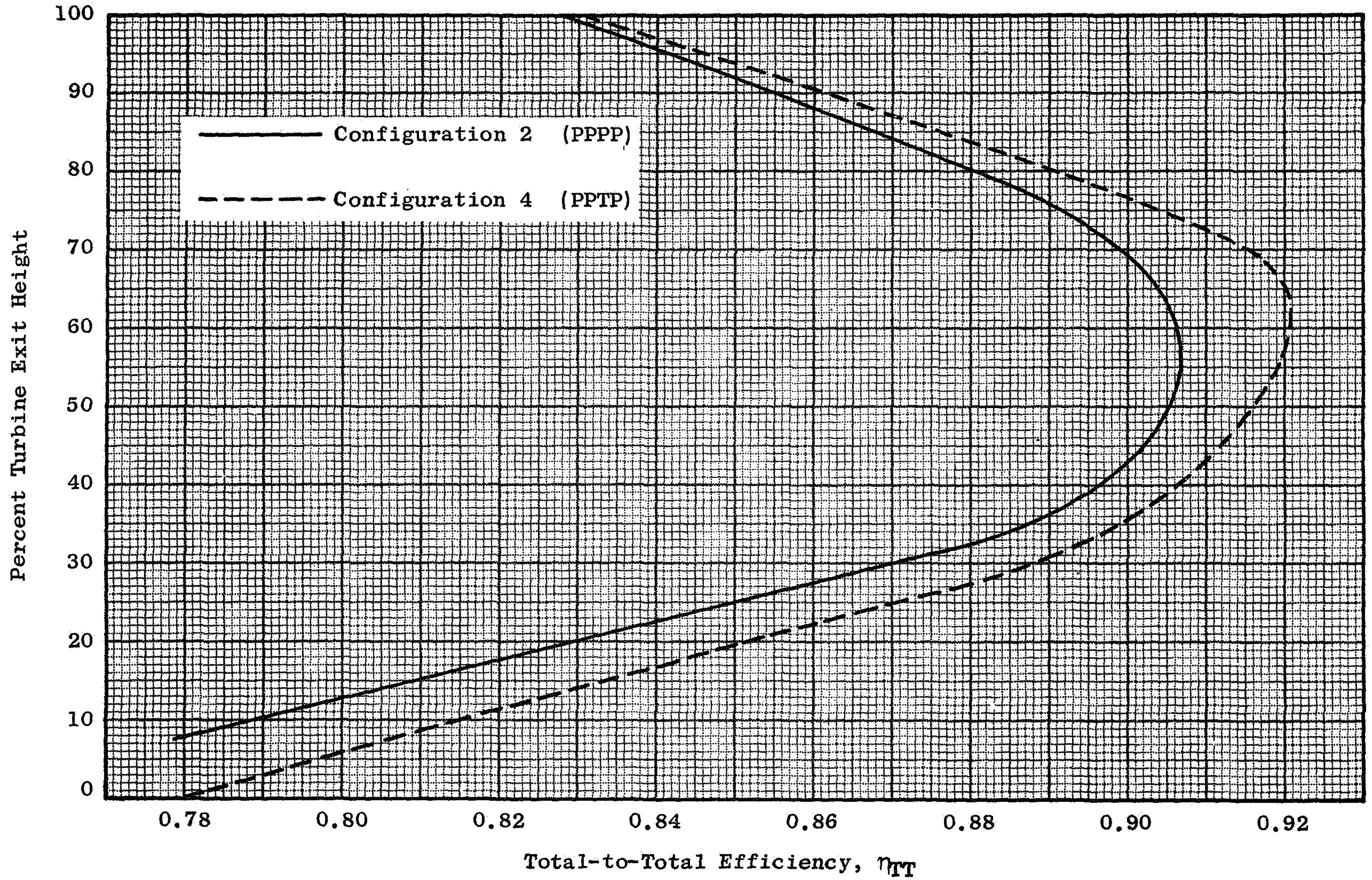


Figure 105. Radial Efficiency Profile, Configuration 4 (PPTP) Compared with Configuration 2 (PPPP).

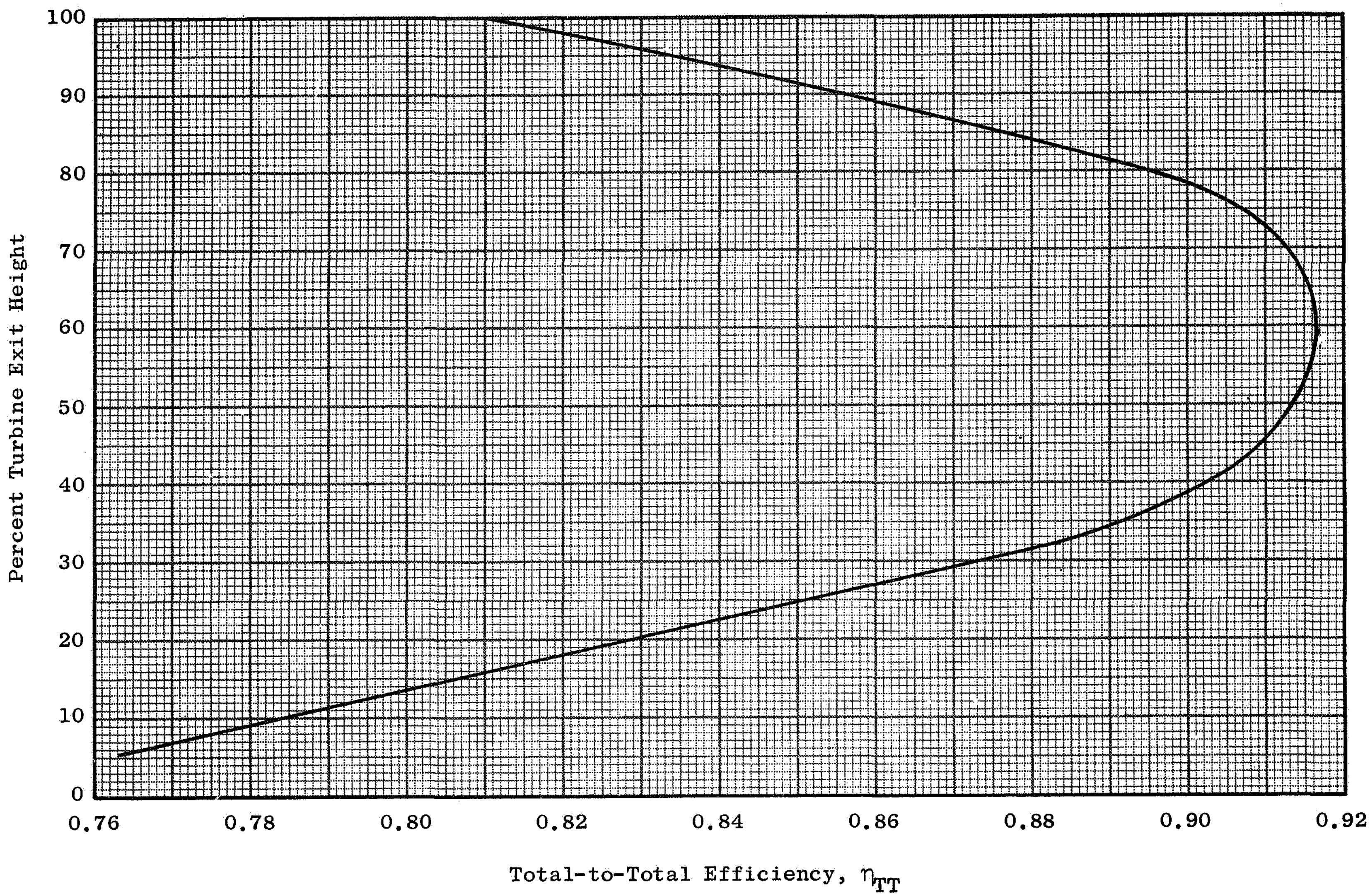


Figure 106. Radial Efficiency Profile, Configuration 3 (PP).

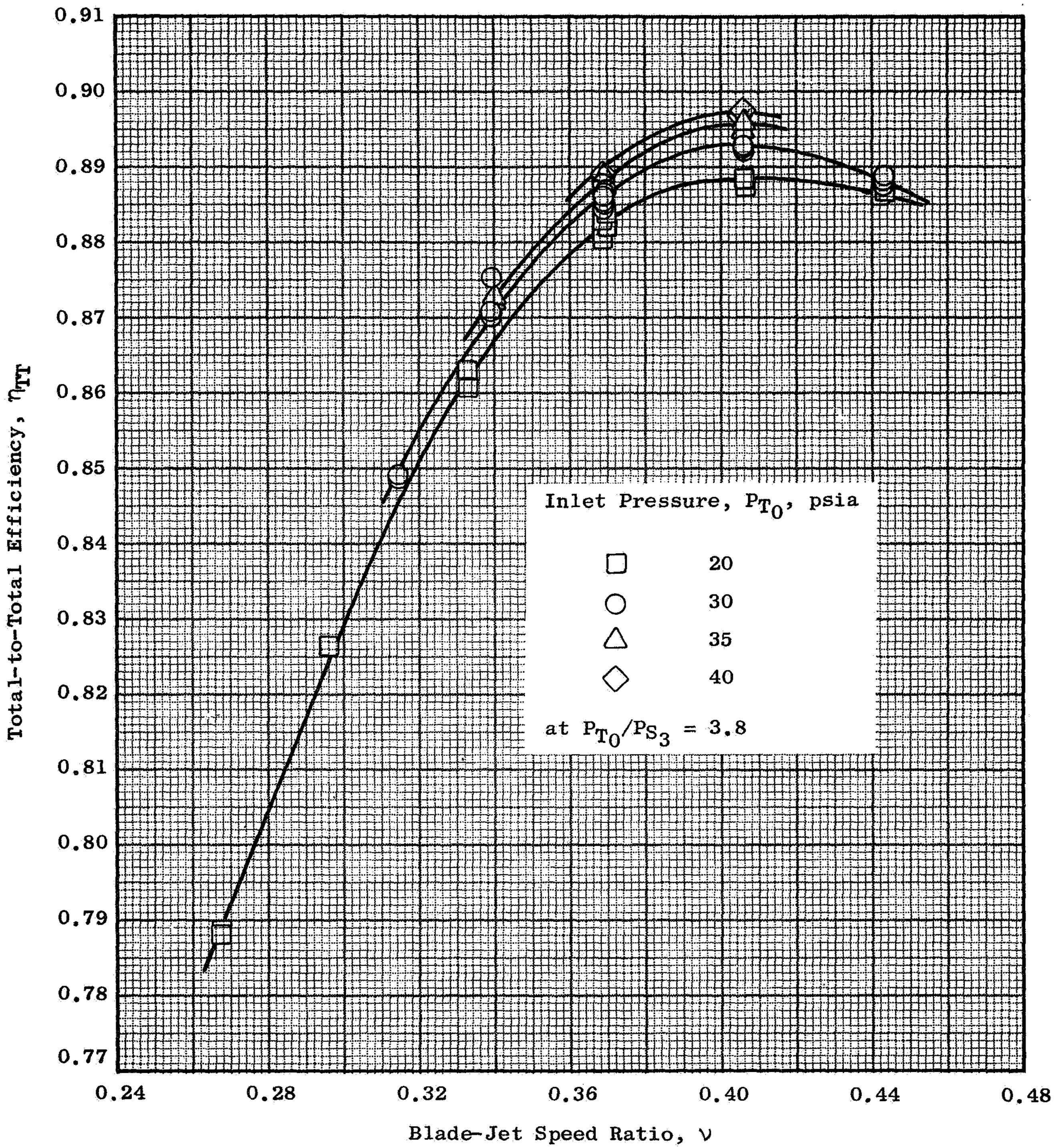


Figure 107. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 1 (PPPPPP).

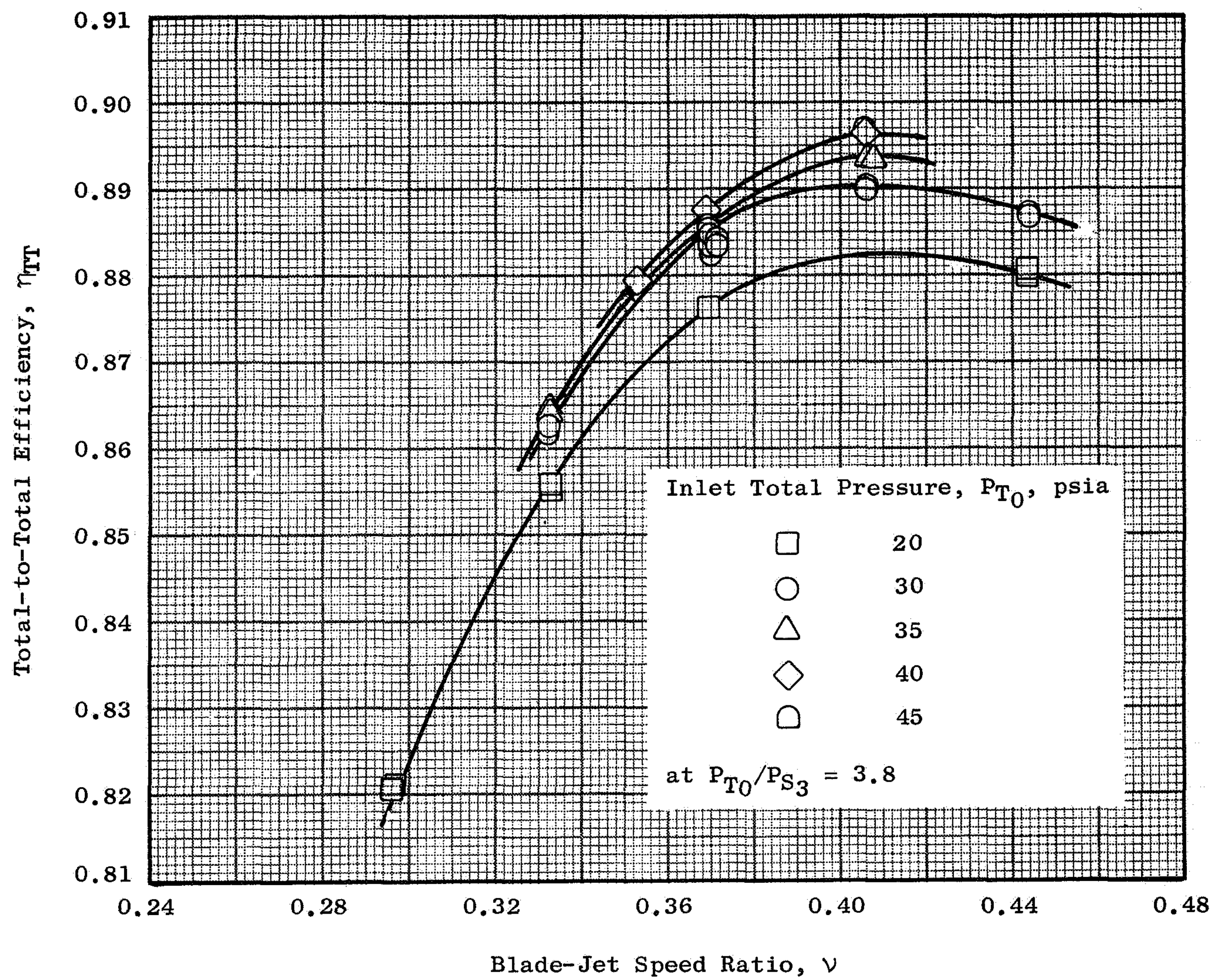


Figure 108. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 5 (PPPPPT).

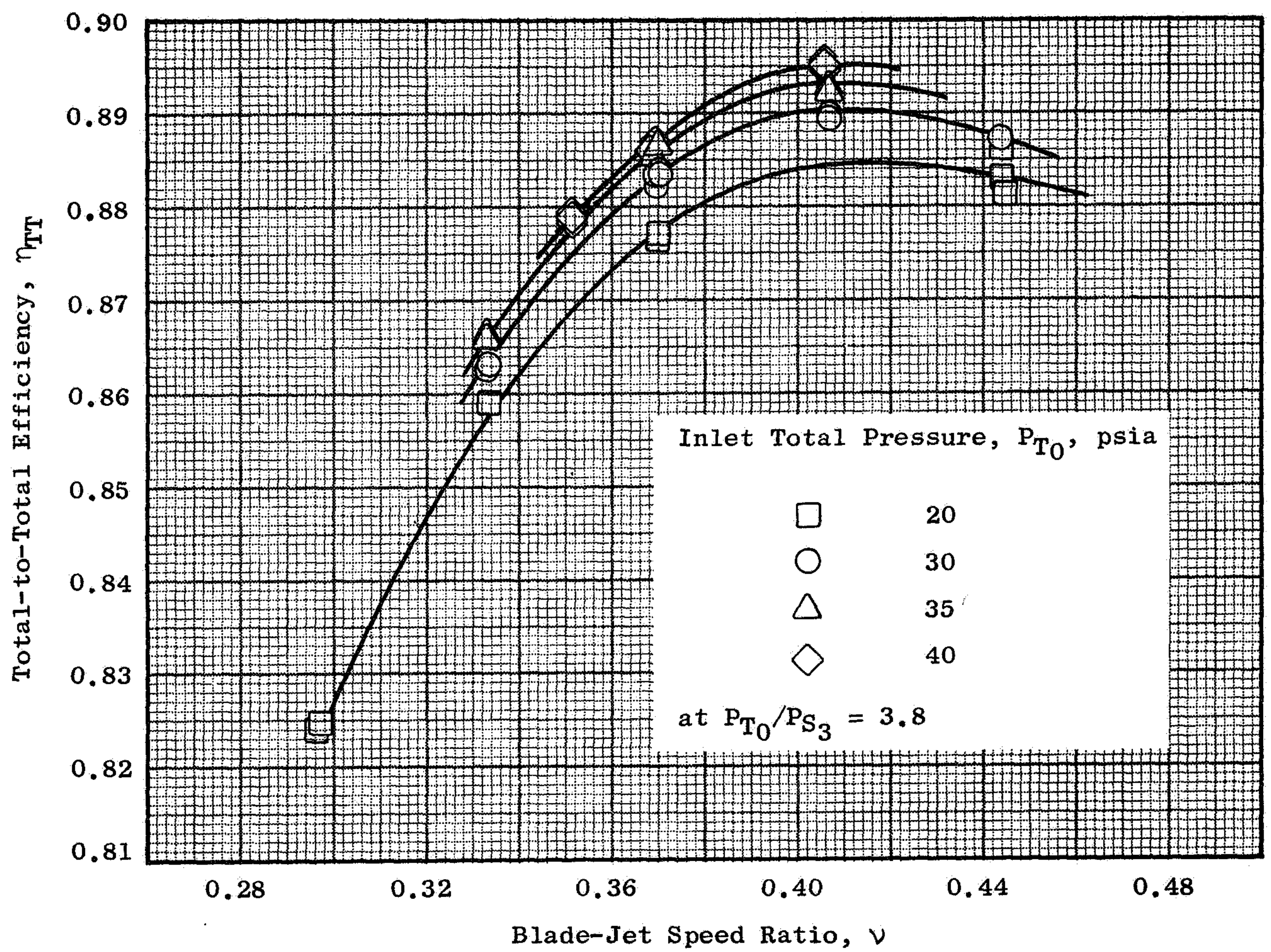


Figure 109. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 6 (PPTPTT).

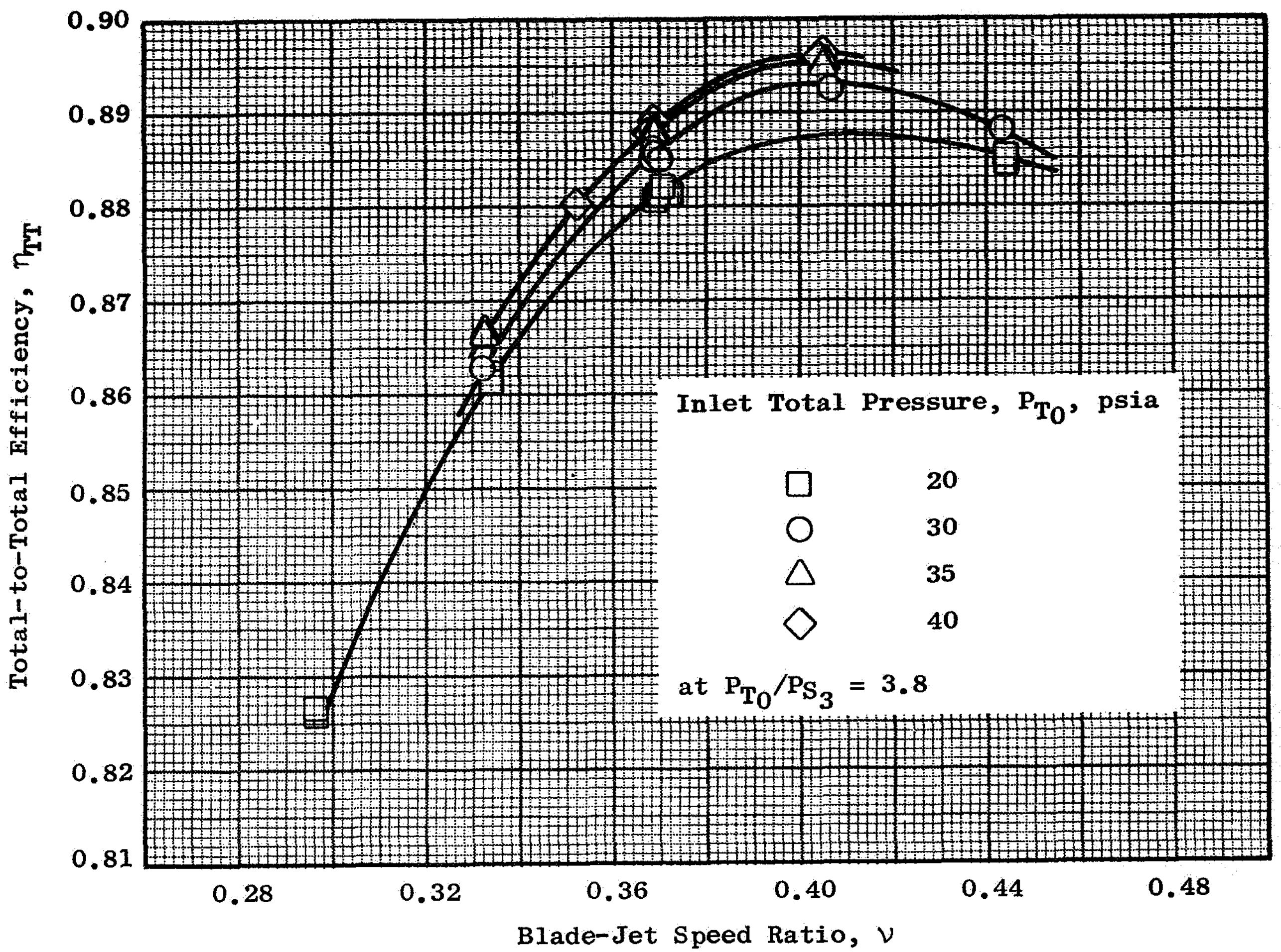


Figure 110. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 7 (PPPPLP).

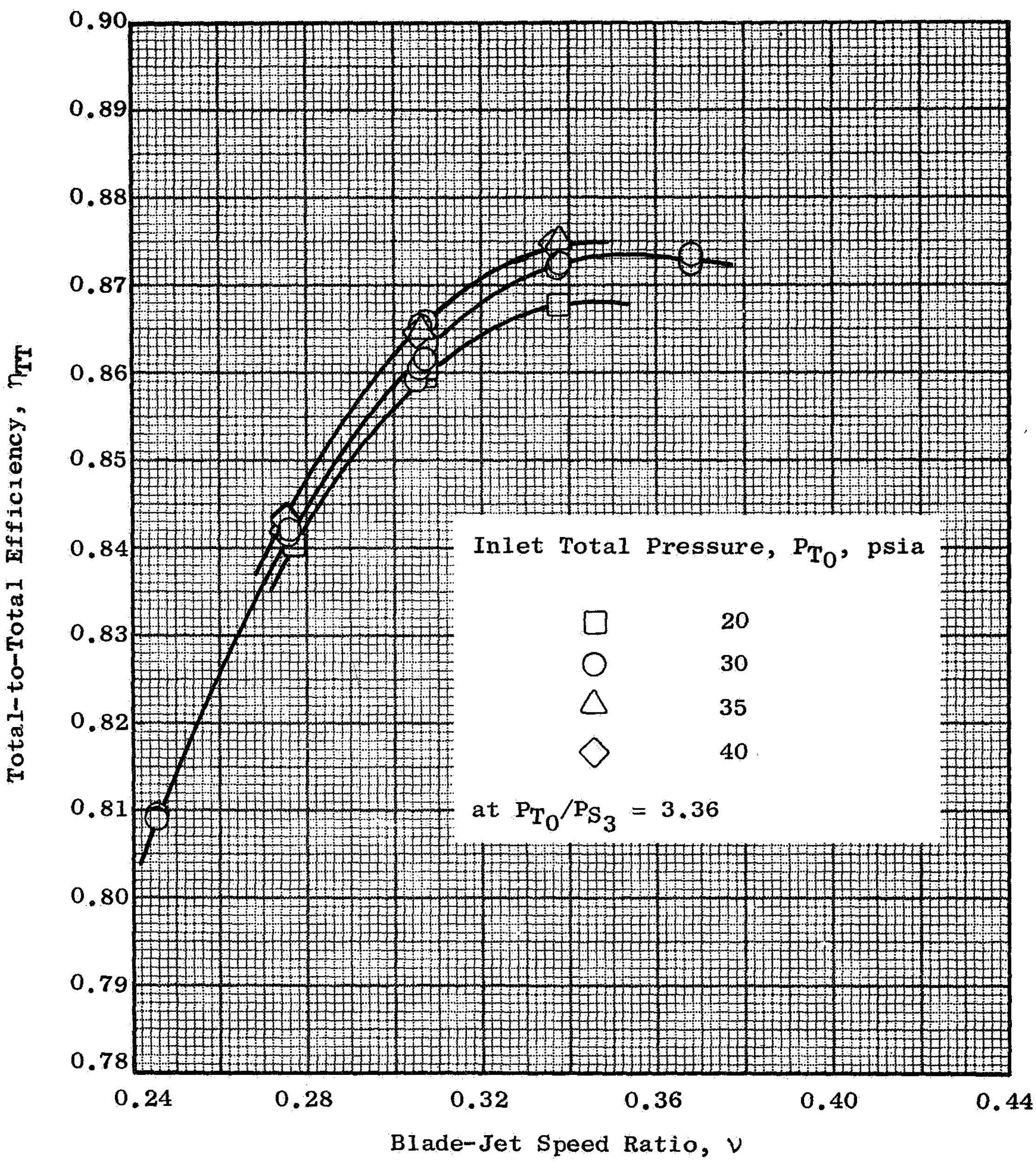


Figure 111. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 2 (PPPP).

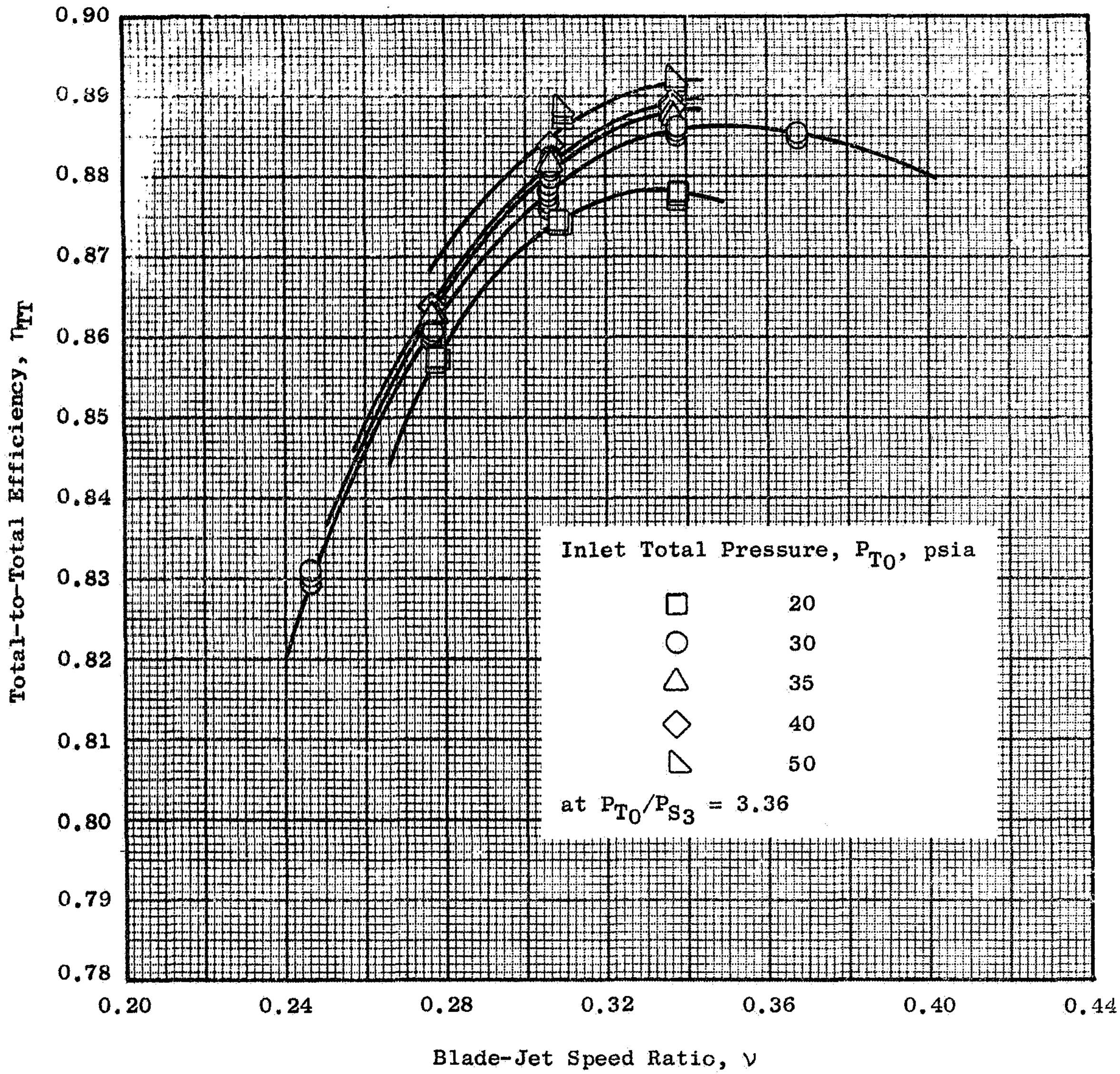


Figure 112. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 4 (PPTP).

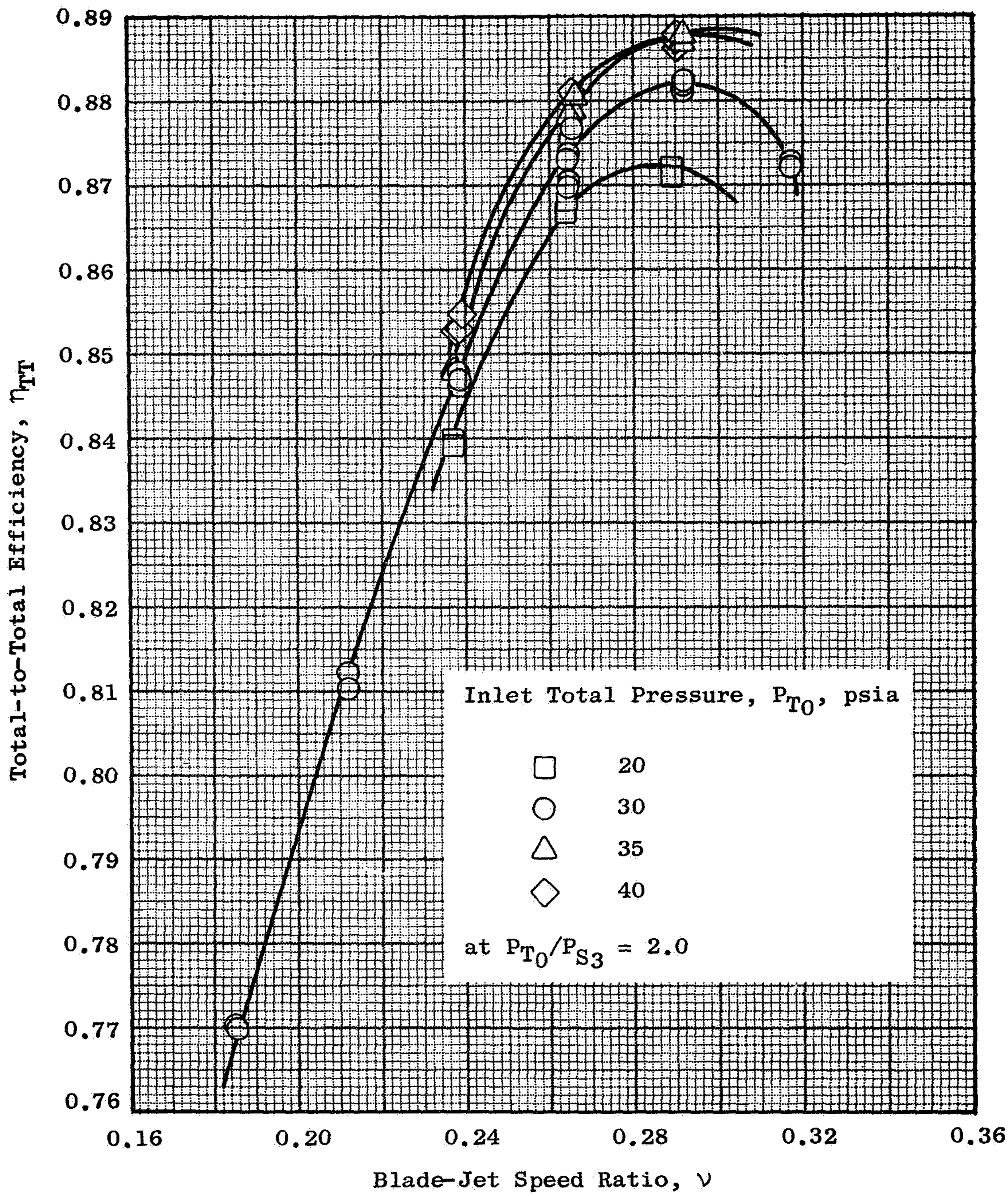


Figure 113. Total-to-Total Efficiency Vs. Blade-Jet Speed Ratio for Various Inlet Pressures, Configuration 3 (PP).

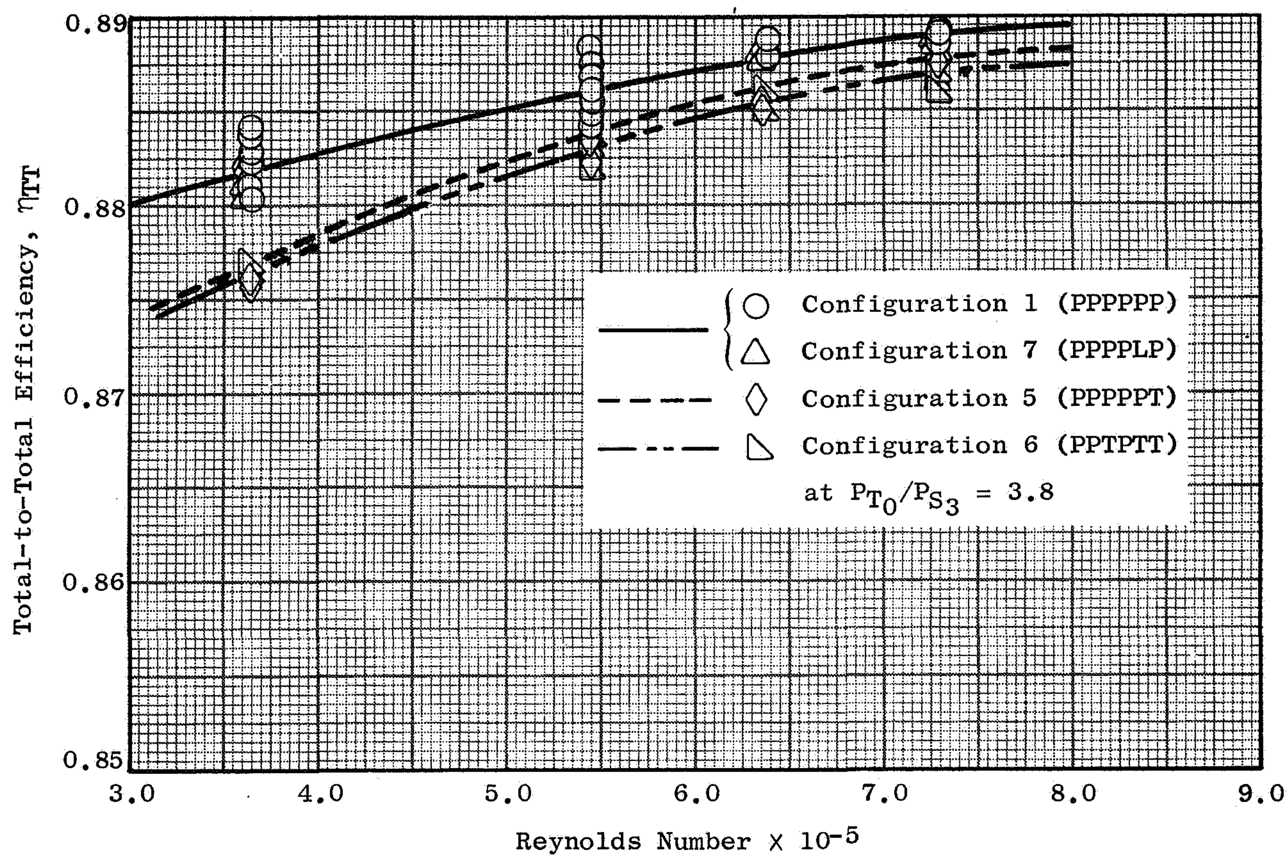


Figure 114. Total-to-Total Efficiency Vs. Reynolds Number at Design Equivalent Speed, Three-Stage Turbine Configurations.

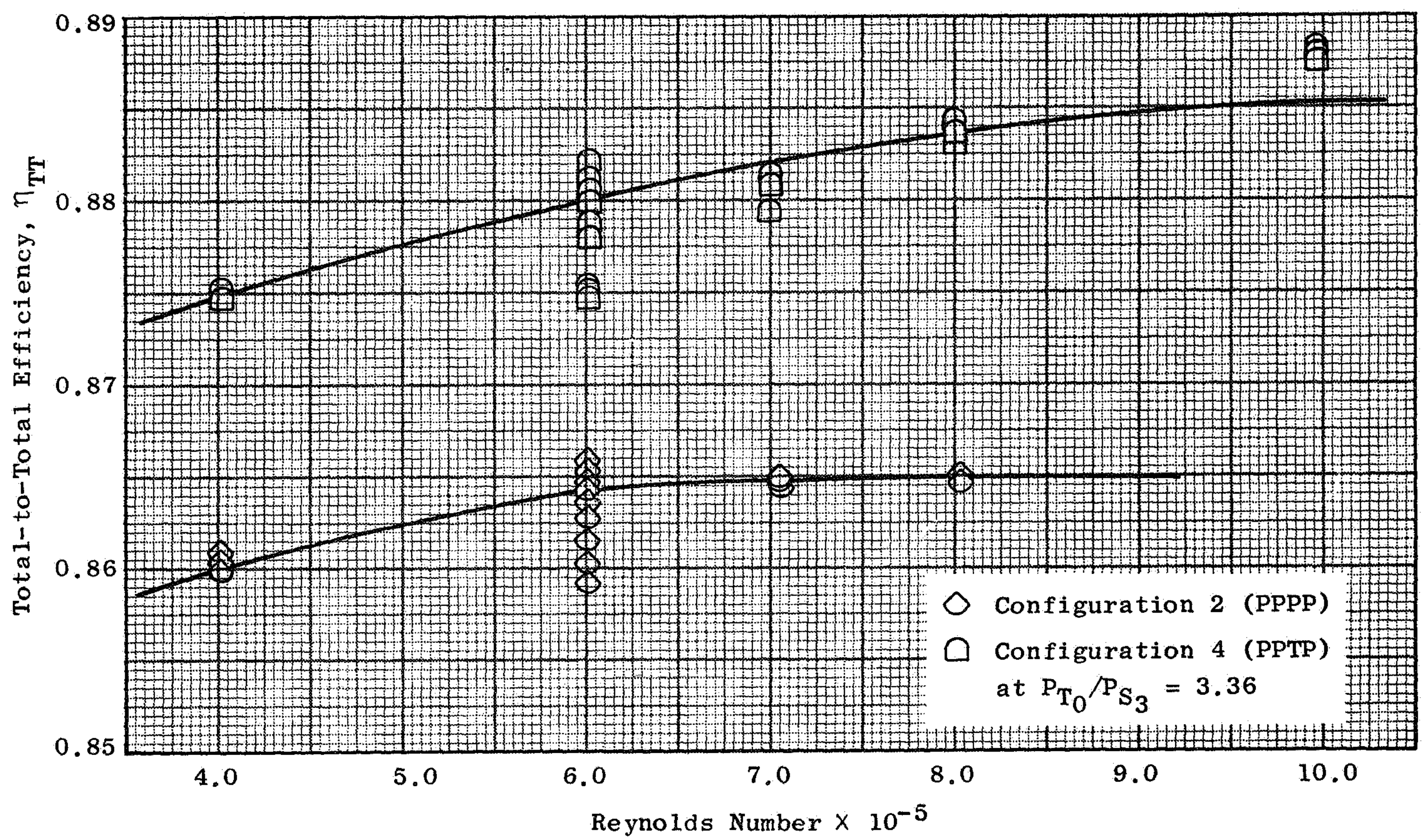


Figure 115. Total-to-Total Efficiency Vs. Reynolds Number at Design Equivalent Speed, Two-Stage Turbine Configurations.

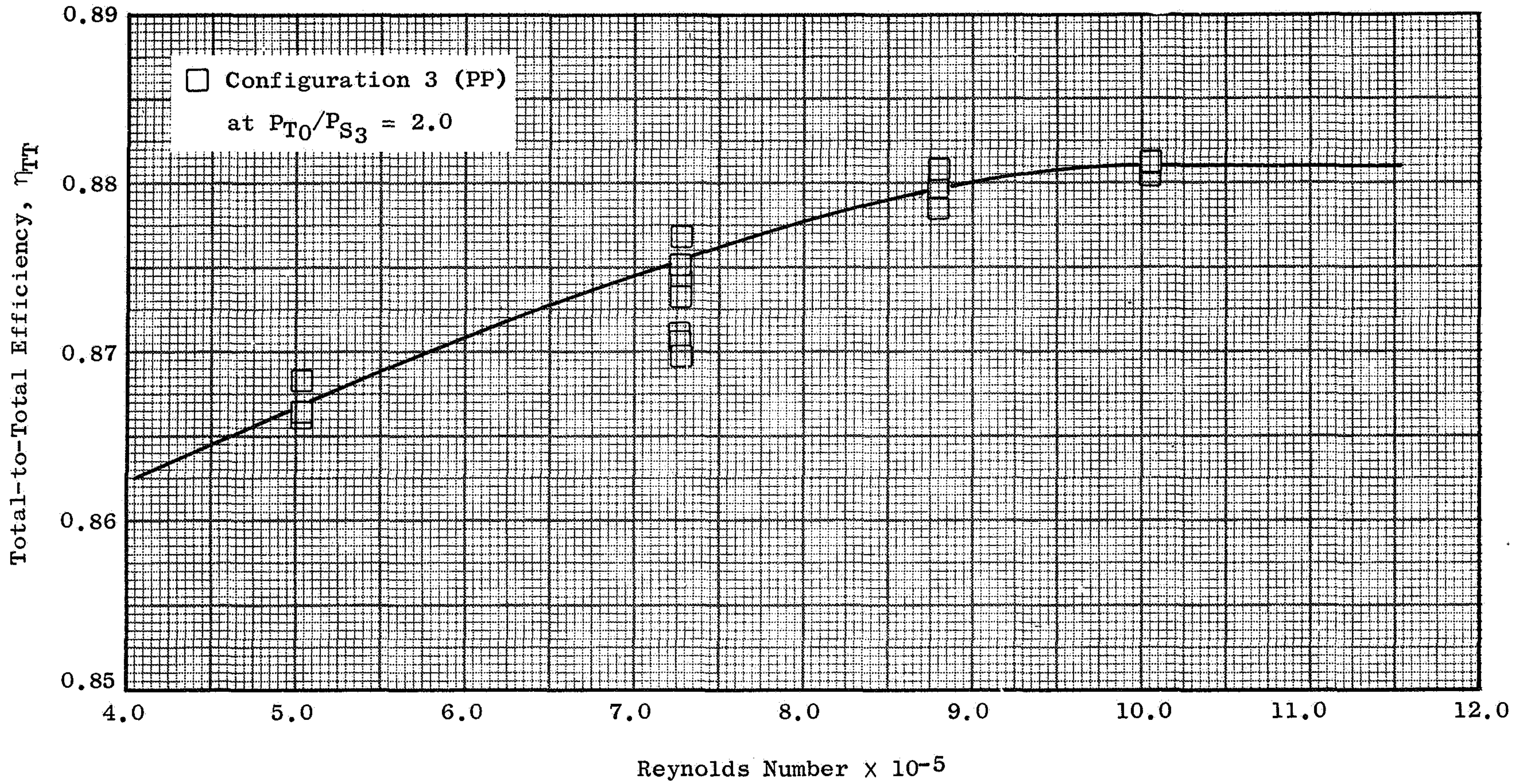


Figure 116. Total-to-Total Efficiency Vs. Reynolds Number at Design Equvalent Speed, One-Stage Turbine Configuration.

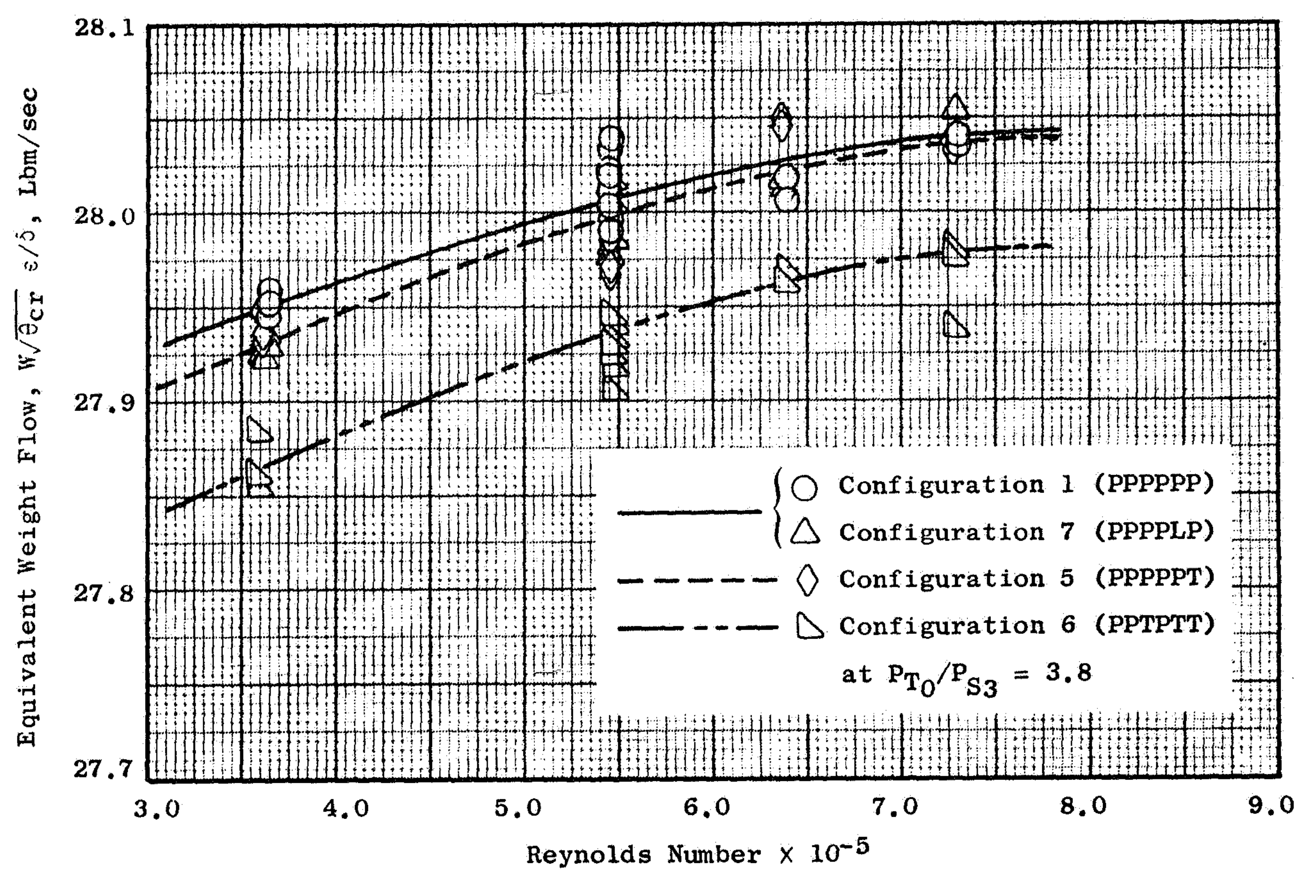


Figure 117. Equivalent Weight Flow Vs. Reynolds Number at Design Equivalent Speed, Three-Stage Turbine Configurations.

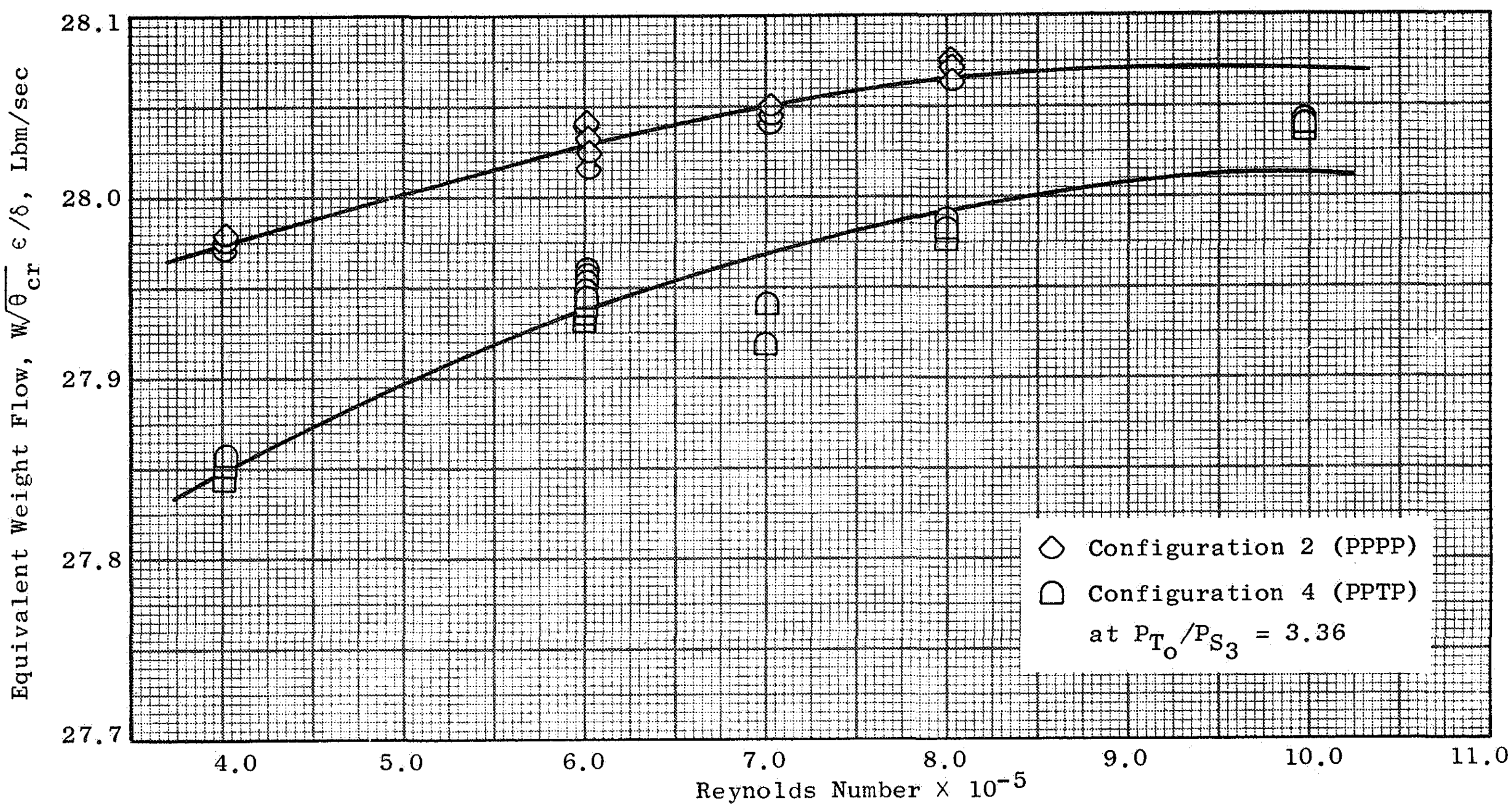


Figure 118. Equivalent Weight Flow Vs. Reynolds Number at Design Equivalent Speed, Two-Stage Turbine Configurations.

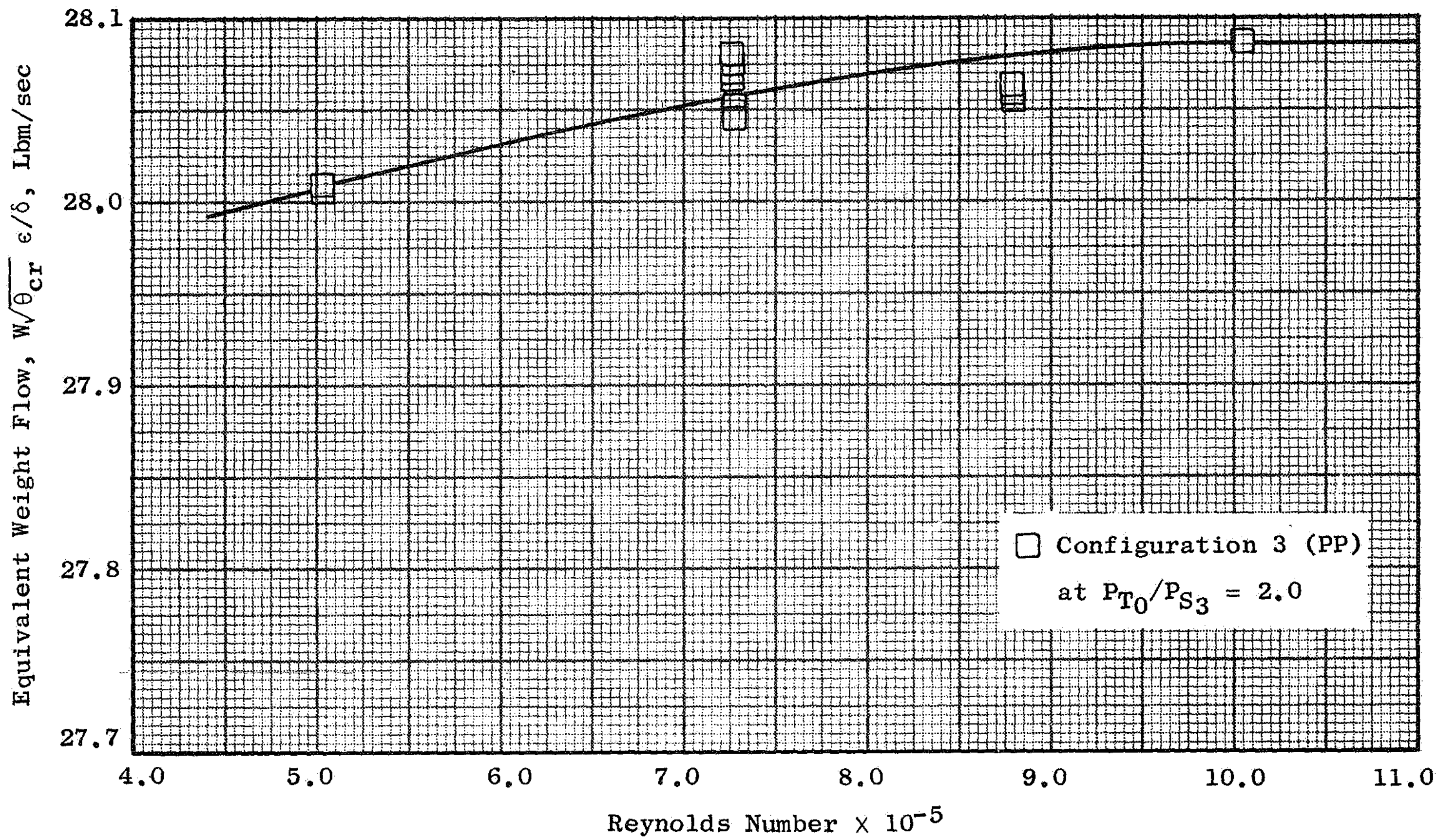
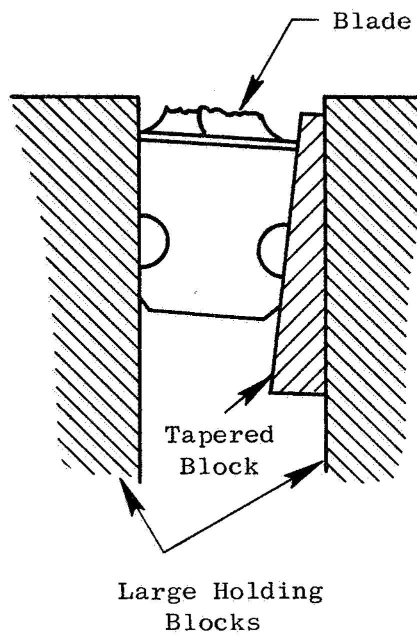
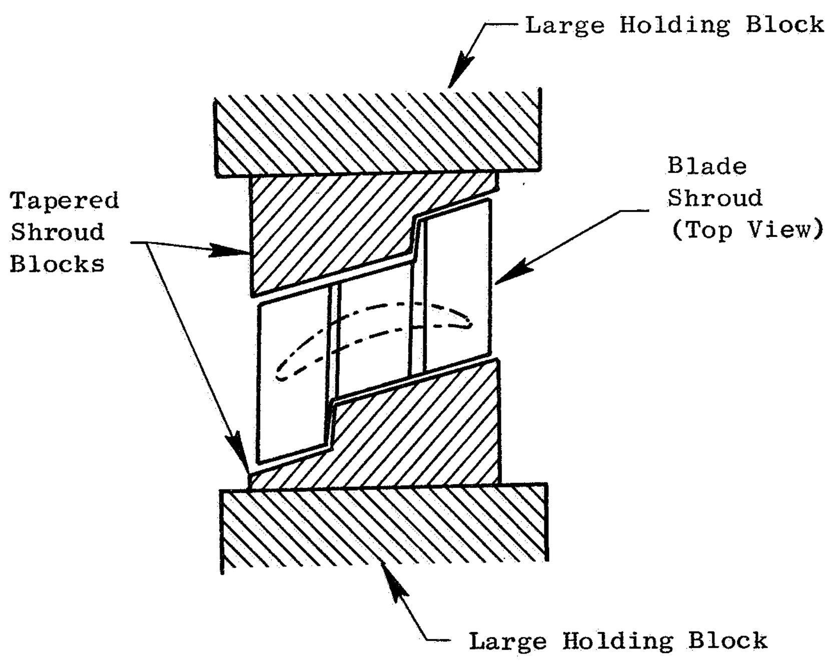


Figure 119. Equivalent Weight Flow Vs. Reynolds Number at Design Equivalent Speed, One-Stage Turbine Configuration.



a. Hub Dovetail Clamp



b. Tipshroud Clamp

Figure 120. Blade Clamping Conditions for Frequency Testing.

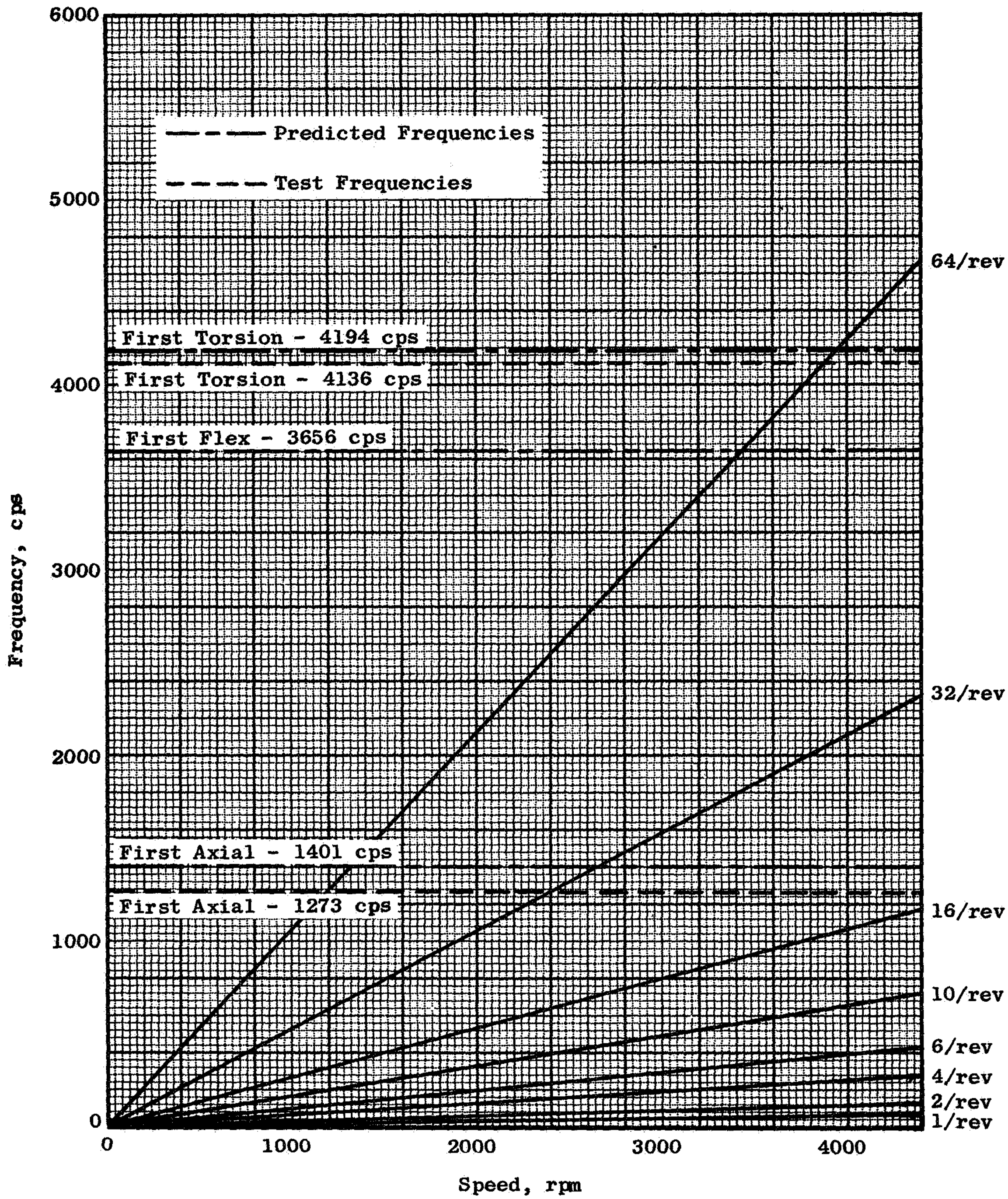


Figure 121. Most Probable Modes of Vibration, Stage One Plain Blade.

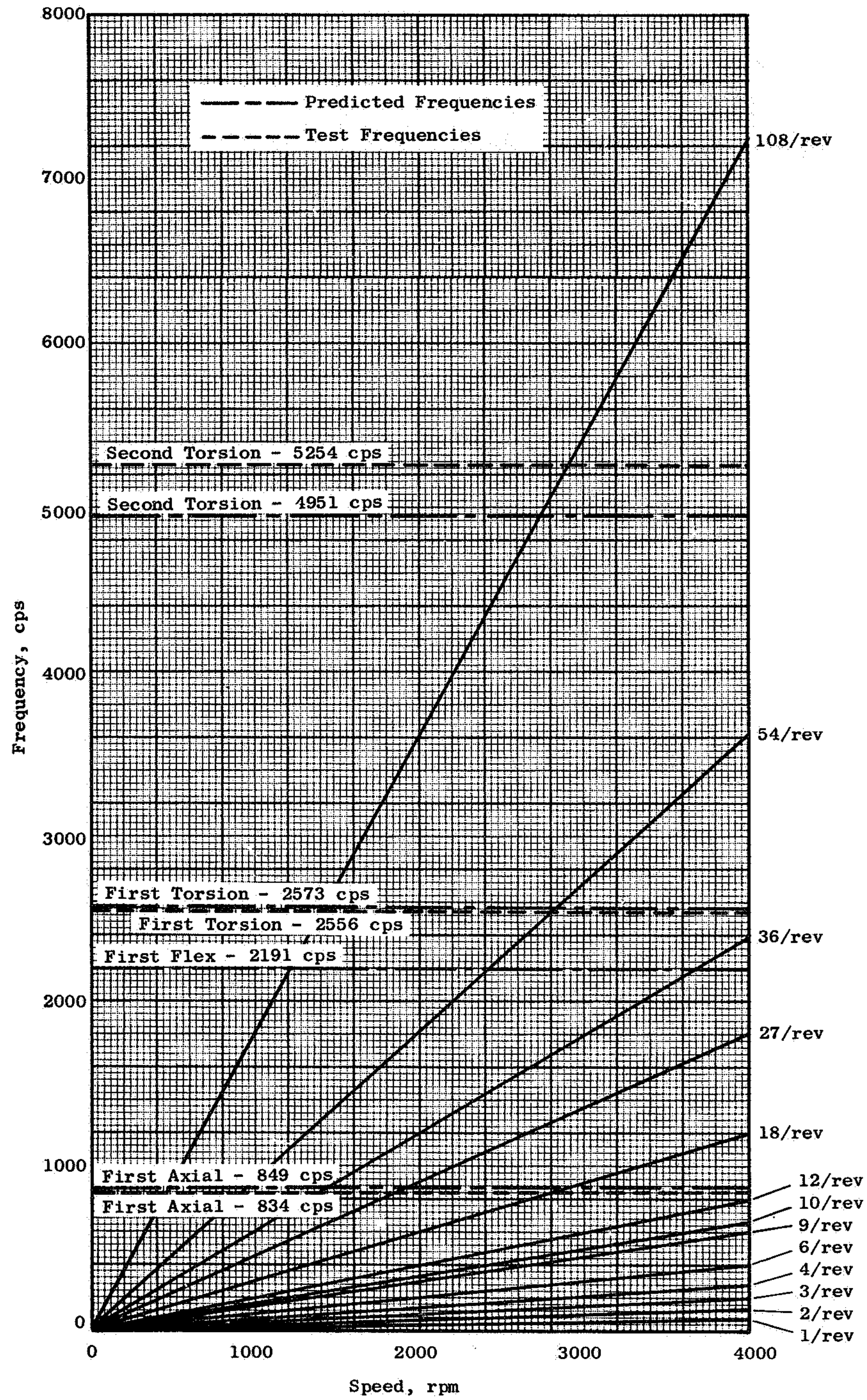


Figure 122. Most Probable Modes of Vibration, Stage Two Plain Blade.

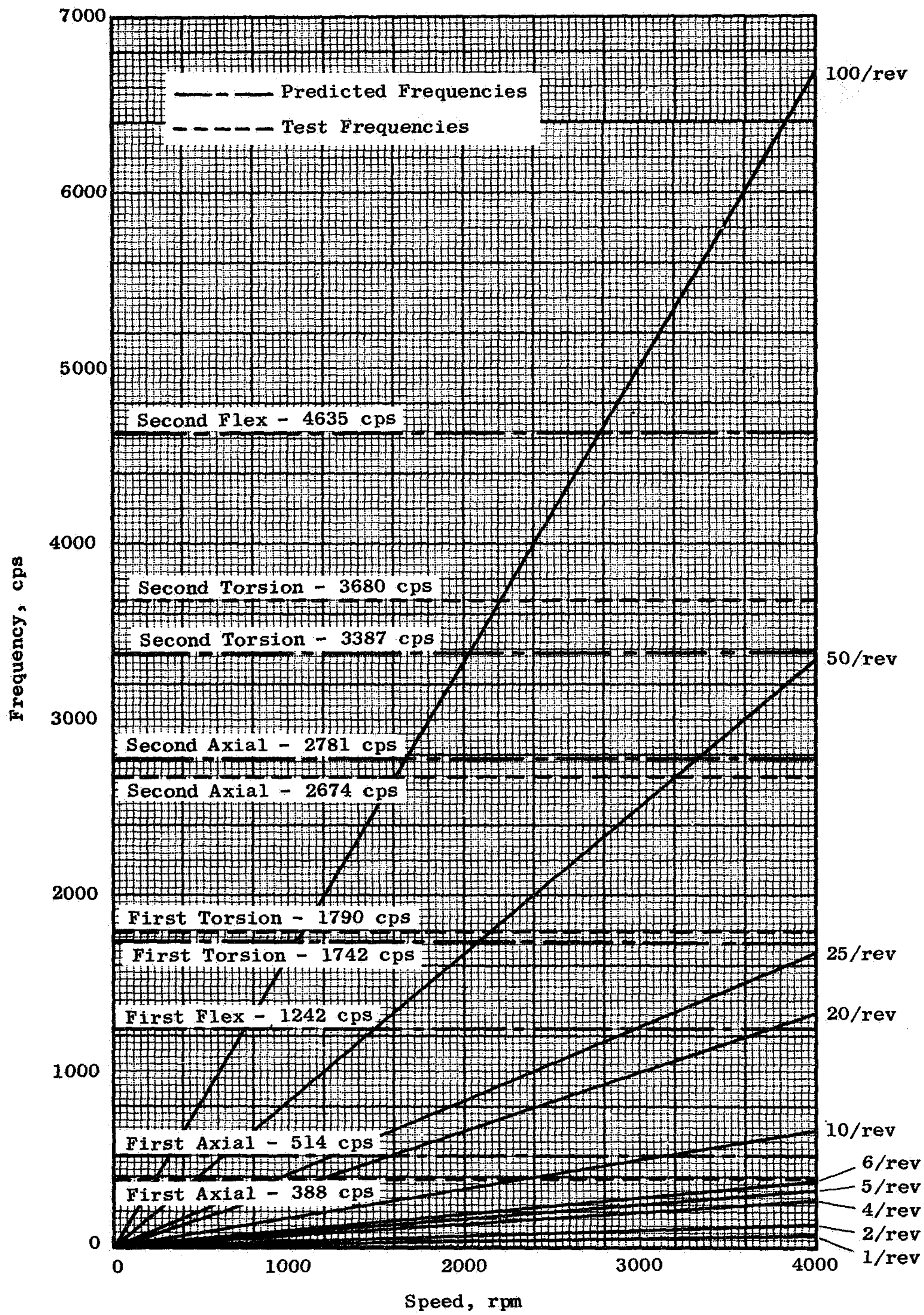
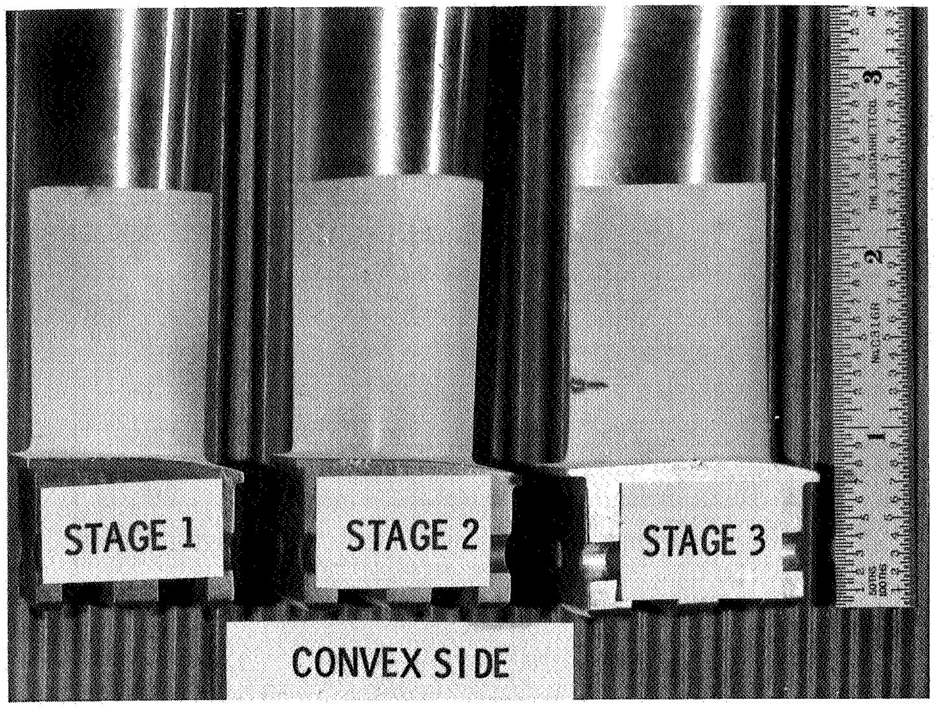
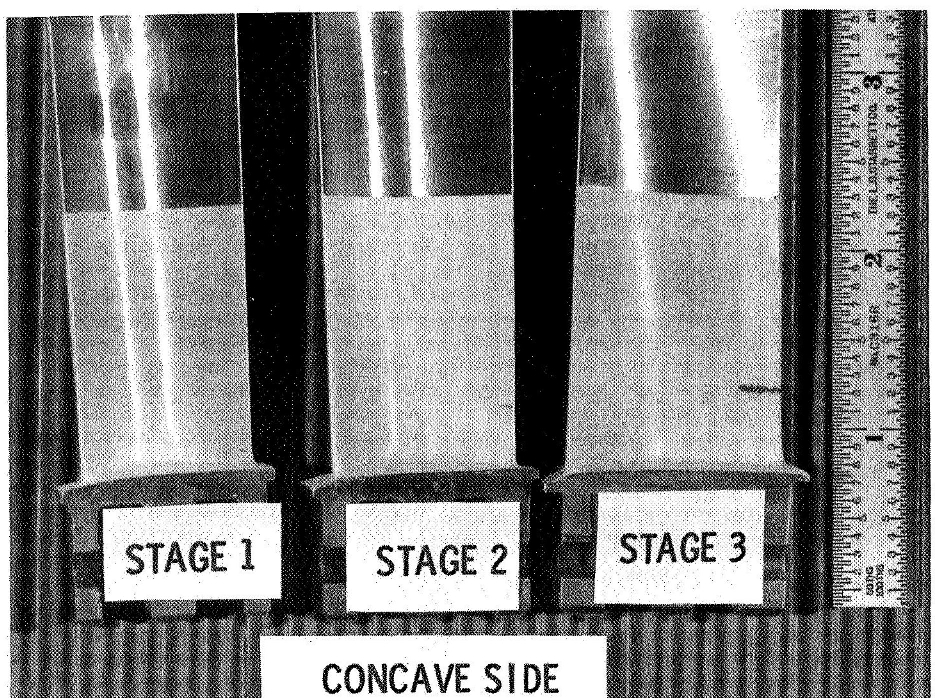


Figure 123. Most Probable Modes of Vibration, Stage Three Plain Blade.



Suction Surface

Figure 124. Fatigue Endurance Test Blade Failures, Plain Blade Suction Surfaces.



Pressure Surface

Figure 125. Fatigue Endurance Test Blade Failures, Plain Blade Pressure Surfaces.

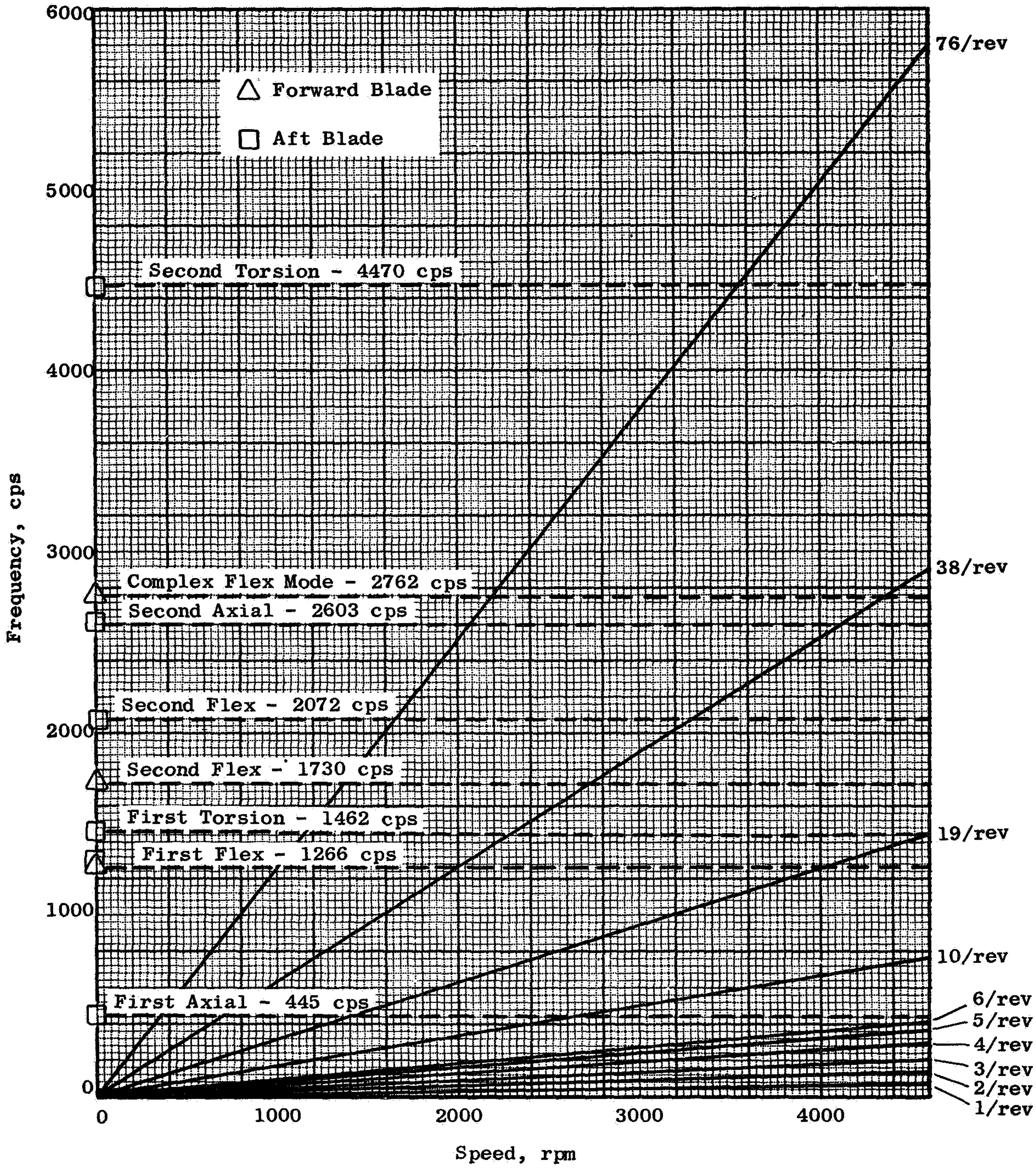


Figure 126. Most Probable Modes of Vibration, Stage Three Tandem Blade Preceded by 76 Vane Stator.

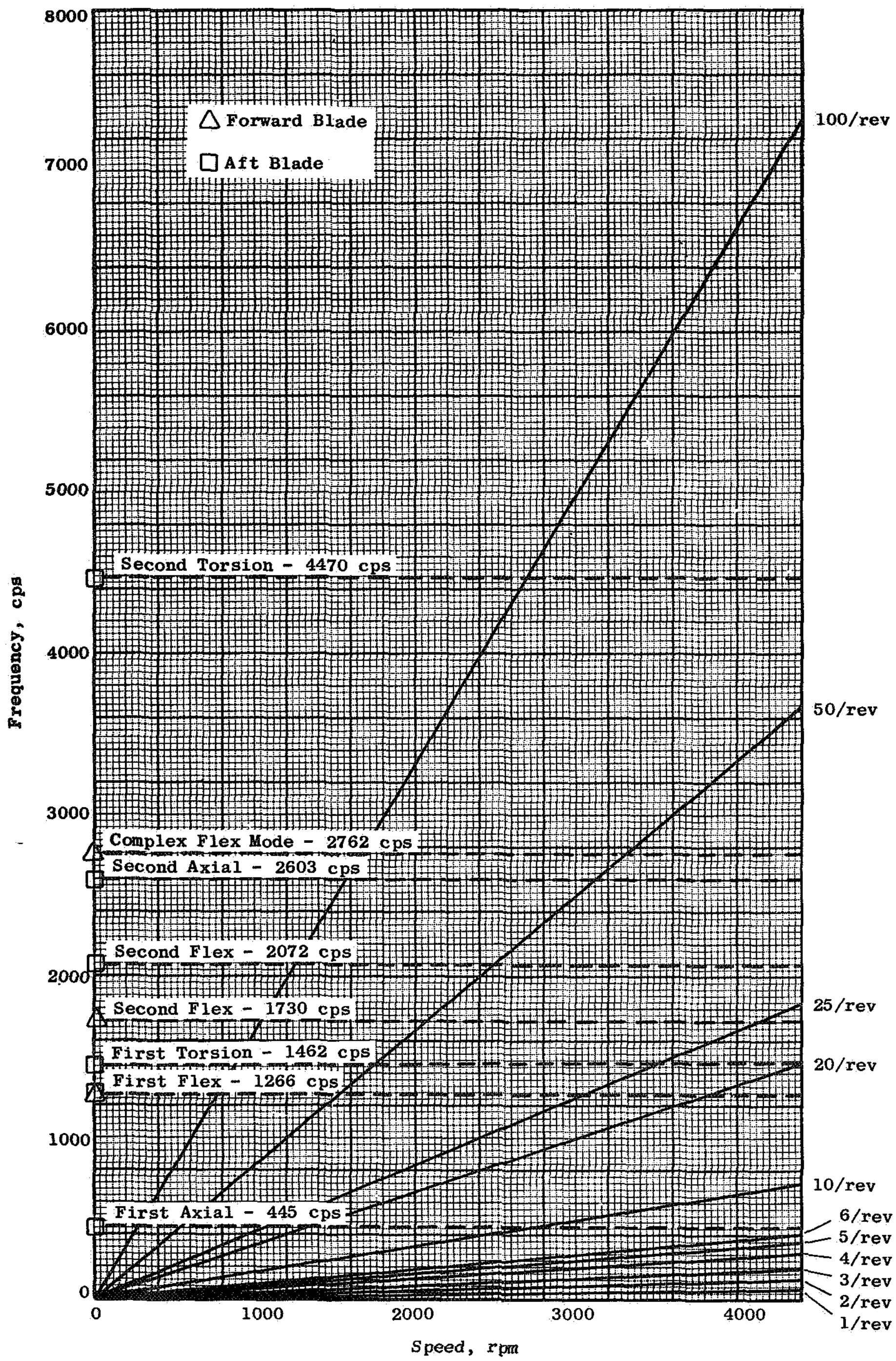


Figure 127. Most Probable Modes of Vibration, Stage Three Tandem Blade Preceded by 100 Vane Stator.

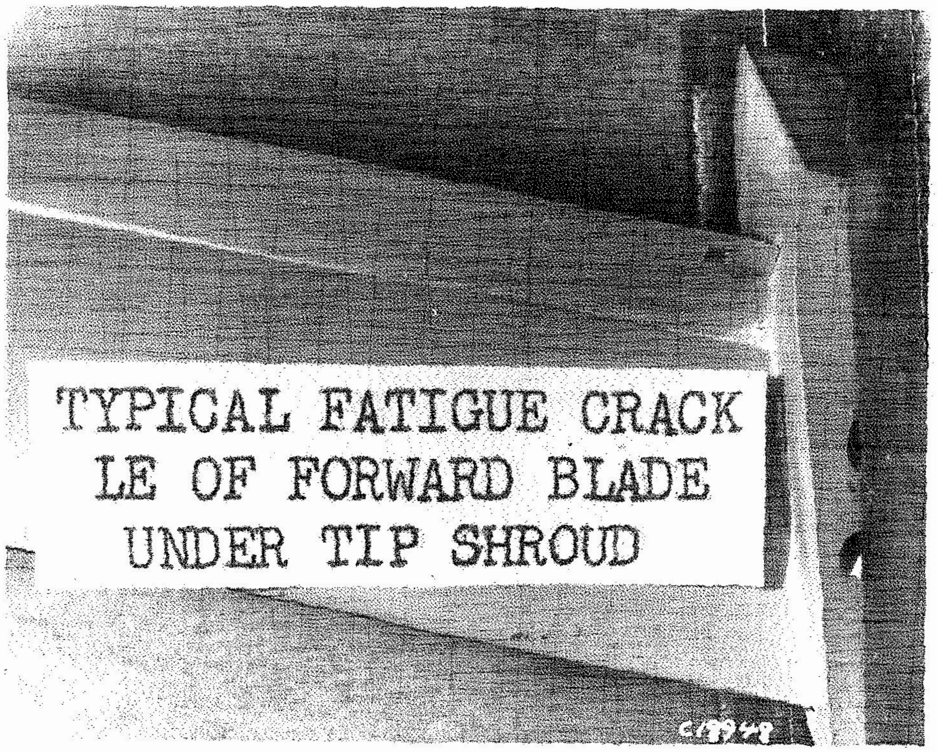


Figure 128. Fatigue Endurance Test Blade Failure, Tandem Blade Pressure Surface.

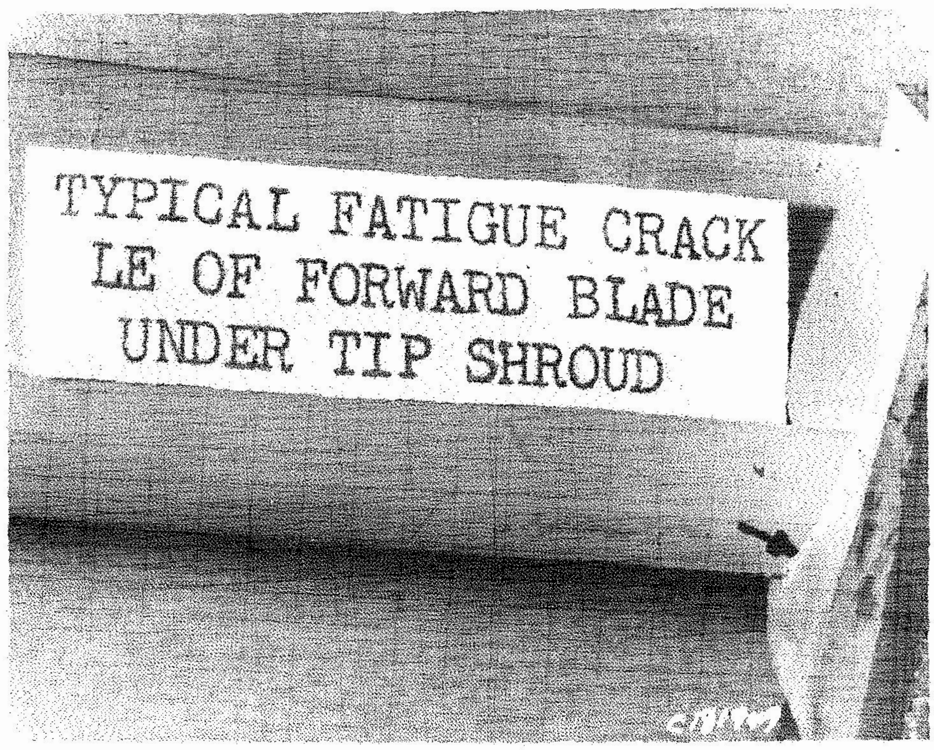


Figure 129. Fatigue Endurance Test Blade Failure, Tandem Blade Suction Surface.

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